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Barrier Technology Handbook

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BARRIER TECHNOLOGY HANDBOOK

Nuclear Security Systems 1700
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

This handbook presents evaluations of barriers which can be used to delay unwarranted penetration into fixed site facilities that house nuclear material. Barriers of conventional construction, upgrades to those barriers, and new types of barriers are considered. Total penetration times and individual task rates are included.

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CHAPTER 1

INTRODUCTION

PURPOSE OF HANDBOOK

This barrier handbook has been prepared as a companion document to other safeguards handbooks.[1-5] The purpose of this handbook is

1. To define the role of barriers in a physical protection system.

2. To provide a central source of penetration times for barriers for physical protection systems effectiveness evaluations and for use by designers, and

3. To define methods for upgrading existing barriers and to define advanced concepts for new or replacement barriers with increased penetration times.

Penetration times have been developed by three methods:

1. Literature Search. Where considered pertinent, data developed by other agencies are included in this handbook.

2. Prototype Testing. Penetration times of test barriers for various attack modes have been measured.

3. Estimates. This method establishes penetration times based on extrapolated or interpolated data from similar barrier tests and/or penetration rates given in Chapter 15: "Penetration Rates and Data Base."

When it has been considered feasible, actual barriers have been constructed and subjected to various attack modes by special attack teams composed of volunteers with excellent health, physical strength, and stamina. These teams are provided with the necessary tools and equipment, plan their methods, and stage the attacks. Trained observers record the actual penetration time for each attack. Appropriate penetration data are lacking for many types of barriers. Because of this lack of data, some sections of this handbook are limited to qualitative discussions of available options. Some barriers have received extensive evaluations, some have received only a small amount of evaluation, and some have not yet been evaluated.

Barrier evaluation to date has addressed

1. Those types of barriers for which data are lacking, and

2. New barriers which appear promising.

Maintaining a barrier data base is an integral part of the barrier evaluation program. As additional data become available, the data base will be revised.

ACKNOWLEDGMENT

Information is based on data obtained from evaluation programs conducted by

- The Department of Defense (Defense Nuclear Agency and Departments of Army and Navy)

- The Department of Energy (Office of Safeguards and Security—Sandia Laboratories)

- Other Government Agencies

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1. *Entry-Control Systems Handbook,* SAND77-1033 (Albuquerque: Sandia Laboratories, revised October 1978 and September 1980).

2. *Intrusion Detection Systems Handbook,* SAND76-0554 (Albuquerque: Sandia Laboratories, revised October 1977, updated January 1979).

3. David L. Poli, *Security Seal Handbook,* SAND78-0400 (Albuquerque: Sandia Laboratories, December 1978).

4. *Safeguards Control and Communication Systems Handbook*. SAND78-1785 (Albuquerque: Sandia Laboratories, May 1979).

5. Joseph V. Williams, *Lock Handbook (U)*, SAND78-0500 (Albuquerque: Sandia Laboratories, June 1979, revised December 1980) (CNSI).

CHAPTER 2

ROLE OF BARRIERS

ELEMENTS OF A PHYSICAL PROTECTION SYSTEM

Four elements, which must react in a timely manner, form the foundation for an effective physical protection system:

1. *Detection and Assessment* systems must detect and verify any unauthorized intrusion attempt by outsiders or any serious malevolent acts by insiders or outsiders.

2. *Communication* systems must ensure that all pertinent information is transferred to the point(s) where appropriate action can be taken.

3. *Delay* systems (barriers) must impede continued adversary penetration into, or exit from, the area being protected.

4. *Response* systems, or forces, must counteract adversary activity and neutralize the threat.

These elements are equally important and none of them can be eliminated or compromised if an effective physical protection system is to be achieved. Detection, which encompasses not only intrusion detection but also entry control, is an important element since any delay scheme can eventually be penetrated, and, without detection, the response force would not be alerted. Delay elements must provide sufficient time after detection to allow the response force to arrive. Finally, the response force must be adequately prepared to neutralize the adversary actions.

A simple graphical method of illustrating the timely interplay of these four elements, and particularly the role of barriers, in a physical protection system is shown in Figure 2-1.

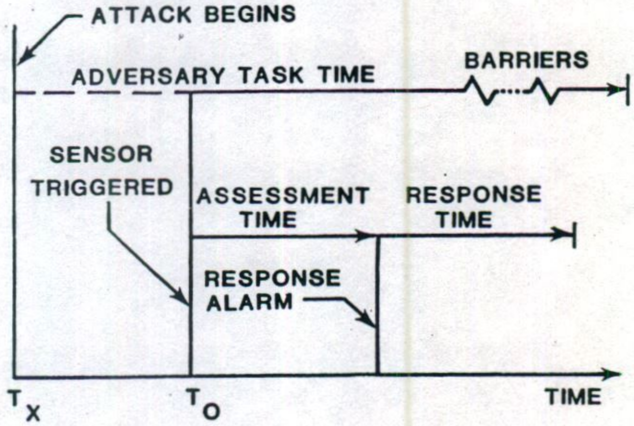

Figure 2-1. Role of Barriers in a Physical Protection System

At some point in time, labeled T_x, the attack or unauthorized action by the adversary begins. The upper vector in Figure 2-1 reflects the actions and time required for the adversary to complete his goal if not delayed by guard force actions. The initial portion of this vector is shown as a dashed line indicating that no alarm has yet been triggered and that the adversary actions are covert. At time T_o, a sensor is triggered which will initiate the active protection system elements. Commencing at time T_o, a time race begins between the adversary and the response elements. The protection system objective is to ensure that the sensor alarm is quickly and correctly assessed and that sufficient response forces are alerted and arrive at the proper location in time to prevent the adversary from accomplishing his goal.

The role of barriers is simply to increase the adversary task time that remains after the detection system sensor is triggered. This increase in adversary task time is accomplished by introducing sufficient impediments along all possible adversary paths to provide the needed delay for the response forces to arrive and react.

ASSUMED THREAT ATTRIBUTES FOR BARRIER EVALUATION

Adversaries have the option of using tactics of force, stealth, or deceit,* or combinations of these tactics. The barrier evaluation program is primarily directed toward adversary tactics of force or stealth. Entry-control systems address deceit. The threat goals may be either sabotage of equipment or materials to achieve the dispersal of radioactive materials or theft of sensitive materials. For barrier evaluation, the potential threat is assumed to be an outside terroristlike group capable of assault with competence level ranging up to that of a paramilitary group. The following excerpt is one definition of such threat:

> With respect to external threats, safeguards should be able to protect with high confidence against "determined violent assault." These threats would be substantially greater than "professional armed robberies" in terms of adversary numbers, armament, and motivation. They would consist of armed terrorist-type groups. Such safeguards should also include the capability to protect against fanatics who would have no inhibitions whatsoever about killing and would continue their attack to the last man.[1]

The threat could also be an insider (authorized personnel) who either works alone or in collaboration with an outsider group. The insider is assumed to be capable of force, stealth, or deceit tactics.

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*Force—Adversary actions that attempt to defeat the physical protection systems by overt aggressive activities during which the adversary is not concerned with being detected.

Stealth—Adversary actions that attempt to defeat the physical protection system by avoiding or inactivating its components in an attempt to prevent detection.

Deceit—Adversary actions that attempt to defeat the physical protection system with the expectation that unauthorized conditions, such as false credentials will not be detected.

BARRIER PHILOSOPHY

With the exception of a few barriers provided by natural elements such as rugged coastlines, high cliffs, mountaintops, and vast distances, physical protection must be provided by barriers that are carefully planned and positioned in the path of the adversary. The degree of delay afforded depends upon the nature of the physical obstacles employed.

To aid alarm assessment and interception of the adversary at predictable locations, consideration should be given to installing barriers and detection systems adjacent to each other so that the barrier is encountered immediately following the alarm. This arrangement serves to delay the adversary at the point of alarm and increases the probability of interception.

The balanced design concept ensures that each aspect of a barrier configuration affords equal access impedance, i.e., there are no weak links. For example, an adversary is not likely to burn a crawl-through hole in a door if the locks or hinges are clearly more vulnerable.

Most security barriers at industrial facilities were designed to deter or defeat sporadic acts of casual thievery. In the environment of escalating terrorist activity, these traditional fences, buildings, doors, and locks may present very little deterrence or delay. The concept of delay is extremely important. Each additional minute required by the adversary provides additional time for response forces to interrupt the action. A few minutes delay may have a significant effect. Ensuring that barriers are in effect around-the-clock (gates and doors must periodically be open or unlocked) may be difficult.

Tests have shown that some structural barriers which have a superficial appearance of impenetrability can be breached quite rapidly by well-equipped and determined adversaries.

A high level of technical skill and the availability of appropriate equipment for penetrating the barrier is assumed. If barrier upgrading follows the balanced design concept, it may result in escalation of the attack tooling requirement to a higher category of tools rather than diversion of the attack path. Upgrading a barrier to force utilization of a higher category of tooling should complicate the logistics, training, and skill required by the adversary, even though the penetration time may not, in some instances change significantly.

PENETRATION ASPECTS

A barrier is penetrated when an individual can pass through, over, under, or around the protective structure. In this handbook, the penetration effort is assumed to start at a distance 2 feet in front of the barrier and to end at a point 2 feet beyond the barrier. Penetration time includes the time to traverse the barrier.

Consideration must be given to the character of the hole (or path) made through a barrier. Rebar cuts may be very jagged, and burn bar cuts may require cooling. Very thick walls require a larger hole for crawl-through than do thin walls.

A vehicle barrier is penetrated (1) when the ramming vehicle has passed through the barrier and is still a functioning vehicle, (2) when a second vehicle has been driven through the breached vehicle barrier, or (3) when the vehicle barrier has been removed or bridged and a functioning vehicle has passed through or over the barrier.

As an adversary encounters a series of progressively more difficult barriers, it becomes increasingly difficult to transport and set up bulky or sophisticated tooling. This is especially true if it becomes necessary to pass through a series of small openings. The accessibility of the target area to vehicular traffic should be considered. When the adversary is forced to carry heavy equipment, such as portable electric generators, for long distances, the delay times may become significant.

Barrier penetration time is a function of the selected attack mode which is governed by equipment required. Categories of attack tooling considered in this handbook are

1. Hand tools—sledges, axes, bolt cutters, wrecking bars, metal cutters,
2. Powered hand tools—hydraulic boltcutters, abrasive saws, electric drills, rotohammers,
3. Thermal cutting tools—oxyacetylene torches, oxylances,
4. Explosives—bulk, linear, and conical-shaped charges, platter charges, and
5. Trucks used as rams.

Figure 2-2 presents a graphic example of a simple scenario for an industrial type facility which uses conventional barriers. This example illustrates how individual barrier penetration times selected from the data base in Chapter 15, "Penetration Rates and Data Base," can be combined with penetration rates to establish total adversary scenario times. The scenario starts with the adversary just outside the fenced area and ends when the adversary has exited the fenced area with the stolen material. In this example, the adversary can accomplish the theft in about 3 minutes, if not interrupted by guards. Guards, of course, may not be available to interrupt the adversary unless he is detected at some point in the scenario, an alarm is sounded, and the guards have time to respond.

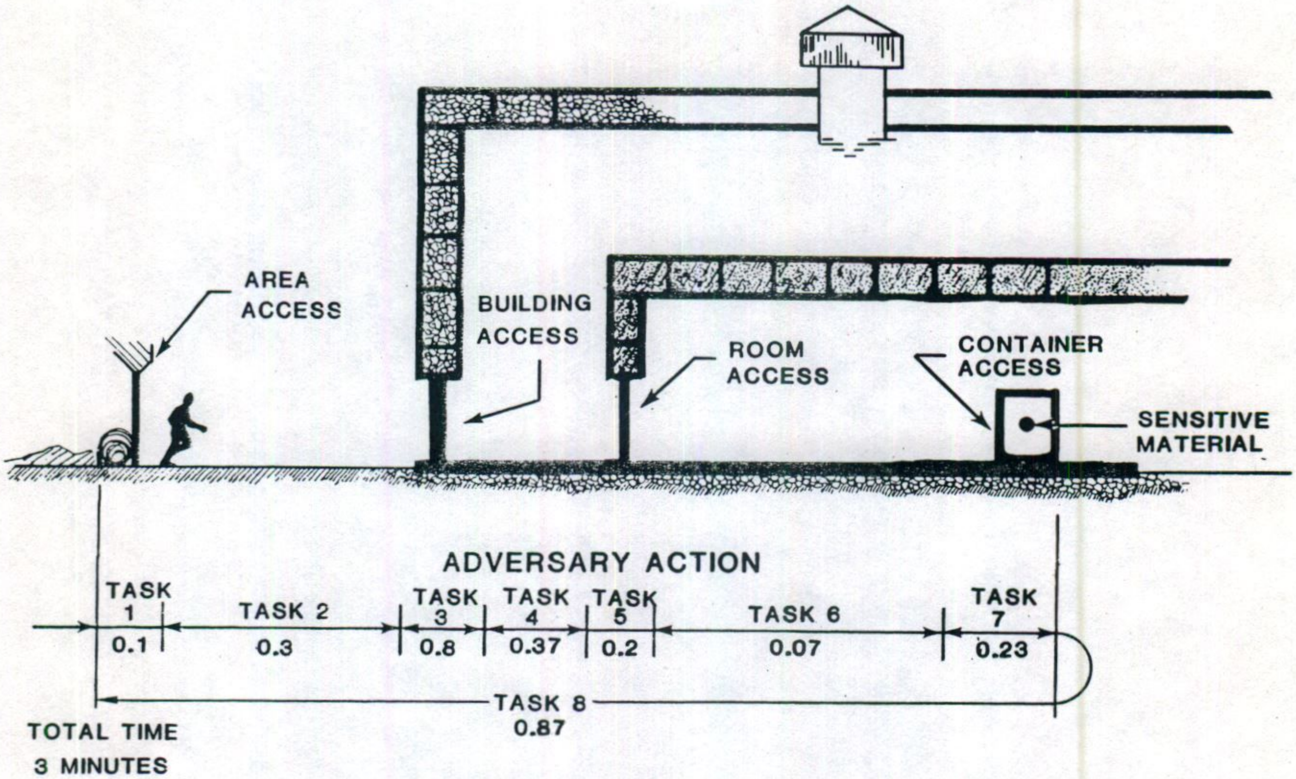
To illustrate the guard response times needed for various protection system goals, assume that a perimeter detection system with an immediate alarm capability exists just inside the fence in the example facility. If the goal is to intercept the adversary before he can penetrate the building, the guards must arrive within about 1 minute of the alarm. If the goal is to intercept the adversary before he can get his hands on the sensitive material (for possible sabotage), the guards must arrive at that location within about 2 minutes of the alarm. If the goal is to prevent removal of the sensitive material from the fenced area, the guards must intercept the adversary within 3 minutes of the alarm.

Because of the short penetration times of many conventional barriers and, therefore, short total adversary scenario times, enhanced or new barriers may be needed to lengthen the delays and gain adequate time for the response force.

More detailed examples of how to use the handbook information to evaluate or select a particular barrier, to develop credible estimates for the penetration delay of a barrier not specifically defined in the handbook, or to develop total unopposed adversary task or scenario times can be found in Chapter 15. The delays listed in the handbook will almost certainly be much longer if response force actions directly interfere with the adversary's penetration effort. In fact, some rather simple barriers, such as fences, would become formidable barriers if lethal fire could be brought to bear on the adversary during attempts to climb over or cut through the barrier.

CONCLUSIONS

A close examination of the large variety of paths or scenarios an adversary can select to penetrate a given facility will probably indicate that existing barriers do not ensure that adversary delay time will always be sufficient for an adequate response force to react. Further, if



Time Estimate

Task	Mean Time (minutes)	Task Description
1	0.1	Climb over fence
2	0.3	Run 250 feet
3	0.8	Force door
4	0.37	Walk 150 feet
5	0.2	Force lock
6	0.07	Walk to container
7	0.23	Open container
8	0.87	Gather material and escape
	2.94	Total (approx. 3 minutes)

Figure 2-2. Example of Forcible Entry

the adversary has not been detected prior to encountering a particular barrier or during penetration, the effectiveness of that barrier may be negligible. Most conventional barriers such as fences, locks, doors, and barriers for windows provide short penetration delay against forcible (and perhaps stealthy) attack methods which do not use explosives. Against thick, reinforced concrete walls and other equally impressive-looking barriers, explosives become an effective, rapid, and more likely method of penetration by the adversary. Ensuring that meaningful barriers are in effect at all times of the day and night may be difficult to accomplish without adversely affecting normal facility operation.

On the positive side, a barrier system can be configured or enhanced to provide effective delay times. For instance, the presence of multiple barriers of different types along all possible adversary paths should complicate the adversary's progress by requiring him to be equipped with a number of different barrier attack tools and skills. Collocating barriers with detection alarms should aid in accurate assessment of and response to threats.

If the facility to be protected has not yet been constructed, barriers can be incorporated into its design. For example, placing the facility either underground or aboveground with massive overburden are options that should be seriously considered. If such a facility is designed with equivalent hardness in entry/exit portals, ventilation, utility ducts, etc., and with appropriate detection systems and response forces, it can be made highly immune to outsider and insider threats, adversary tactics (force, stealth, or deceit), and adversary goals of theft or dispersal sabotage, as well as to the method of transportation used by adversaries (foot, land vehicle, or aircraft) and, to some extent, the size of a terrorist group.

Finally, the use of activated barriers, especially chemical dispensables such as obscurants, irritants, foams, and other debilitating agents (Chapter 13), offers significant potential for increasing adversary delay. These deterrents can be coupled with passive/mechanical structural-type barriers or used as independent barriers. In a unique situation the existing delay time might be greatly increased. Also, conventional breaching techniques and equipment used by an adversary may be so ineffective that he would choose not to continue attacking that barrier. Any activated barrier will, of course, require protection of the complete activation system to avoid or to adequately delay disablement by the adversary.

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Chapter 3

CHAPTER 3

PERIMETER BARRIERS

INTRODUCTION

Perimeter barriers form the outermost protective element of a physical security system and function to exclude unauthorized personnel from an area. Existing barriers, such as fences and gates, may not significantly delay determined adversaries; however, properly designed and positioned barriers could delay personnel and vehicles long enough for other elements of the physical protection system to function, i.e., to detect, assess, respond. This chapter presents results of the evaluation programs to date for various personnel and vehicle barriers. Upgraded designs and advanced concepts for perimeter barriers are included.

The most common type of perimeter barrier is chain-link fencing with gates of comparable materials. Perimeter barriers can be quite extensive and cost per lineal foot should be considered in the initial installation. Most existing industrial-type perimeter barrier systems may be penetrated quite rapidly with simple tools or breached by climbing.

The barrier portion of a physical protection system around a protected area may be developed from the options suggested in this chapter. Consideration should be given to integrating the perimeter barrier and the perimeter detection system. A barrier which provides significant penetration delay may hold the adversary at the point of intrusion long enough to assess the alarm and to allow a response force to intercept the intruder at the point of alarm.

There appear to be many methods of thwarting or significantly delaying vehicle penetrations into a protected area without exorbitant expenditures in equipment and land area. However, providing significant delay for a determined adversary who wants to cross a perimeter barrier on foot is a much more difficult problem and may require significant hardware and land area expenditures if lethal barriers (see p. 3-8) or firepower from guards is not an option.

Improving the penetration resistance of perimeter gates and portals to resist stealthy and forcible penetration, without providing equivalent protection features for the entire perimeter, would not provide balanced perimeter hardness.

STANDARD FENCES

Fences installed around a site can be classified as boundary, temporary, or perimeter installations and are constructed from a variety of materials.

Boundary

A boundary fence is often used to define the outermost limit or border of a facility. Signs are placed on the fence, usually at 50-foot intervals, to show ownership and to warn casual transients of possible dangers within the perimeters. A typical boundary fence is 4 feet high and is constructed of "T" posts to which four strands of barbed wire are installed. This type of fence is often referred to as "cattle fence" and is used only to define a boundary. The boundary fence should not be considered as a physical barrier of any consequence.

Temporary

Temporary fences are installed to deny access to individual areas and are used to enclose construction or storage facilities adjacent to a security area. The construction materials used in this type of fence range from 7-foot-high, 4- by 4-inch wood posts with 6- by 6-inch, 10-gauge mesh to 8-foot-high, 2.375-inch outside diameter steel posts set in concrete with 11-gauge, chain-link mesh, bracing, and 45° extension arms to which three strands of barbed wire are installed.

[redacted] b3

Security

Security fences usually consist of galvanized steel posts, galvanized steel-mesh fabric, and 45° extension arms angled outward to which three strands of barbed wire or coiled concertina wire are installed. Security fences are not usually less than 8 feet high and are braced, as necessary, at all corners, gate openings, or structurally inadequate points. The fabric is usually clamped to a bottom rail or cable. Top and bottom rails are used to help support the fabric, as well as to add to the over all bracing of the fence. These rails, together with all other bracing, are located on the inside of the fabric. All vertical posts are set in circular concrete anchor-footings. In addition to line posts, much heavier corner or terminal posts are used in perimeter fence construction.

Although chain-link fences may serve as a deterrent to casual intruders, they would have very little effect on determined adversaries.

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ENHANCEMENTS

Security fences topped with barbed wire, barbed tape concertina (BTC), or general purpose barbed tape obstacle (GPBTO) do not prevent intrusion. However, if additional rolls of barbed wire or tape are placed on or near existing perimeter fences, penetration can be made more difficult and more time-consuming.

Barbed Wire

Barbed wire has been used for many years as the standard enhancement for most fences. Although it snags and rips clothing, it seldom punctures or lacerates a properly prepared adversary. In addition to its common installation on boundary fences and out riggers on perimeter fences, barbed wire is also formed into concertina coils, depicted in Figure 3-1. Concertina coils are made of single-strand, spring-steel wire with four-point barbs attached every 2 inches.

When extended, the coils are approximately 36 inches in diameter and 50 feet long. Barbed wire strands are formed in the same manner except that barb spacing is lengthened to 3 to 6 inches.

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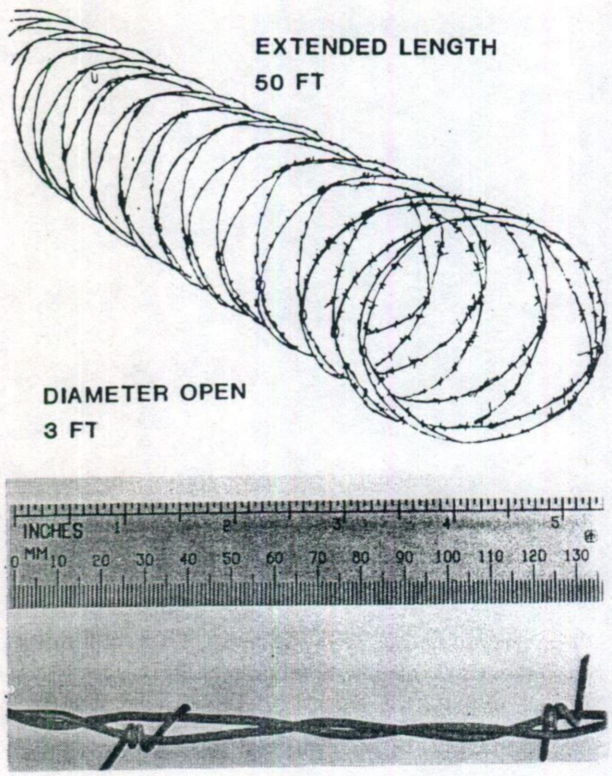

Figure 3-1. Barbed Wire Concertina (BWC). Est. Cost: $0.35/ ft ($1.15/m) [FY 79].

Barbed wire strands are mounted on outriggers and posts by a variety of methods. Some barbed wire is tied to posts and outriggers with soft wire, which is not an effective method. More common methods of attachment consist of diagonal slots in outriggers which contain the wire when pulled taut and standard fabric bands which pinch the wire when tightened. An adjustable tension-tightener is sometimes used at terminal posts to remove sag in the barbed wire strands. Although barbed wire on outriggers presents a psychological deterrent to the casual intruder, it does not prevent determined adversaries from climbing over the fence. Actually, outriggers used for supporting barbed wire and horizontal top rails aid an adversary by supplying him with a handhold to help in climbing over a fence.[3]

Barbed wire concertina (BWC) functions somewhat better than three strands of barbed wire when installed on outriggers because its coiled configuration does not need support. BWC does not need 45° outriggers to support it because it can be attached to chain-link fence fabric with wire ties, "hog rings," or clamps. b3

Barbed Tape

Barbed tape and barbed tape concertina (BTC) were developed by the West Germans during the early 1950s as an improvement to the more vulnerable, single-strand barbed wire. Barbed tape is manufactured in accordance with Military Specification MIL-B-52488 (MO) and assigned National Stock Number (NSN) 5660-921-5517. BTC is manufactured in accordance with Military Specification MIL-C-52489 (MO) and is assigned NSN 5660-921-5516. Barbed tape can be used for the same applications as barbed wire, i.e., on boundary fences and perimeter fences with outriggers. However, the method of attaching barbed tape to posts and outriggers is completely different from the method used for barbed wire. Barbed tape is wider and flatter than barbed wire. As a result, it must be affixed with wire ties or clamps. The same method is used for barbed tape concertina, which is depicted in Figure 3-2.

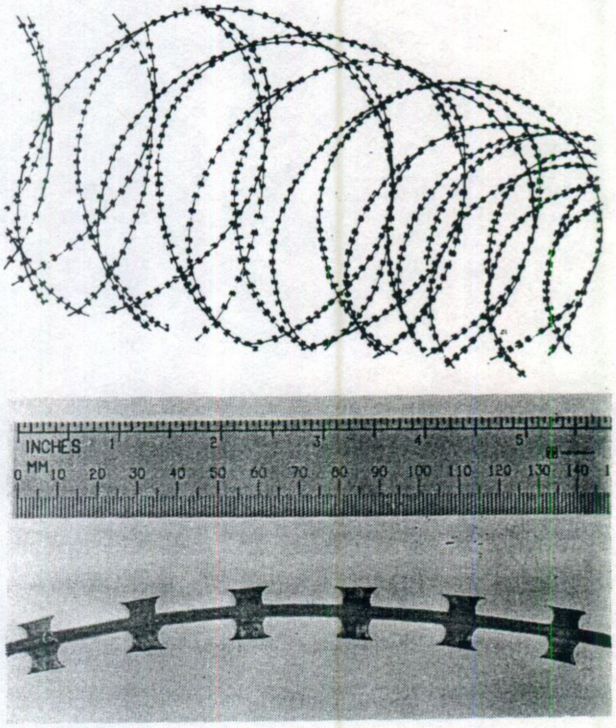

Figure 3-2. Barbed Tape Concertina (BTC). Est. Cost: $0.60/ft ($2.00/m) Single Coil, $1.10/ft ($3.60/m) Double Coil [FY 79].

Barbed tape is fabricated from galvanized steel strips which are 165 feet in length. The strips are wound on plastic reels and can be easily deployed with a barbed tape dispenser. Barbed tape concertina consists of a single strand of spring steel wire and a single strand of barbed tape. The barbed tape is securely affixed around the spring steel wire and coiled into spirals. The spirals are connected by steel clips to form a cylindrical, diamond-shaped coil. BTC is usually 50 feet long and approximately 36 inches in diameter when it is extended (deployed). In addition to use on the tops of fences, BTC can be attached vertically to the chain-link fabric with wire ties. It can also be installed horizontally on the ground behind a fence or between fences in a double-fence installation as an enhancement. When used on the ground, BTC should be anchored with stakes (metal tent pins) every few feet to prevent movement or lifting.

Barbed tape and BTC have been developed to supercede barbed wire in its application on chain-link fences and perimeter barriers. Their barb spacing and design are definite improvements; however, the life expectancy of galvanized barbed tape and BTC may be drastically reduced when they are subjected to high humidity or salt spray. In addition, the barbs are too small to inflict more than superficial scratches and cuts on an intruder. It is possible to crawl through rows of single-coiled BTC with little difficulty, but a deployed double coil with a 36-inch outside diameter and a 24-inch inside diameter makes crawl-through much more difficult and time-consuming. At least one commercial supplier now manufactures stainless steel BTC, and the cost is slightly more than $2/ft — twice as much as galvanized BTC.

General Purpose Barbed Tape Obstacle (GPBTO)

General purpose barbed tape obstacle (GPBTO) was developed by the U.S. Army Mobility Equipment Research and Development Center (USAMERDC) in Ft. Belvoir, Virginia, to improve most characteristics of antiquated BWC and BTC. Figure 3-3 shows a typical GPBTO section. Emphasis was placed on effectiveness, cost, weight, erection simplicity, and emplacement effort.[4,5] The result was a barbed tape with long vicious barbs, easier deployment, less volume and weight, and easier recover ability. Initially, the cost was twice that of BWC and BTC. As of FY 1979, the cost of Type II GPBTO (stainless steel) was nearly three times the cost of double-helix BTC (galvanized steel). GPBTO is manufactured in accordance with Military Specification MIL-B-52775A. There are three types of GPBTO available which are suitable for barrier applications.

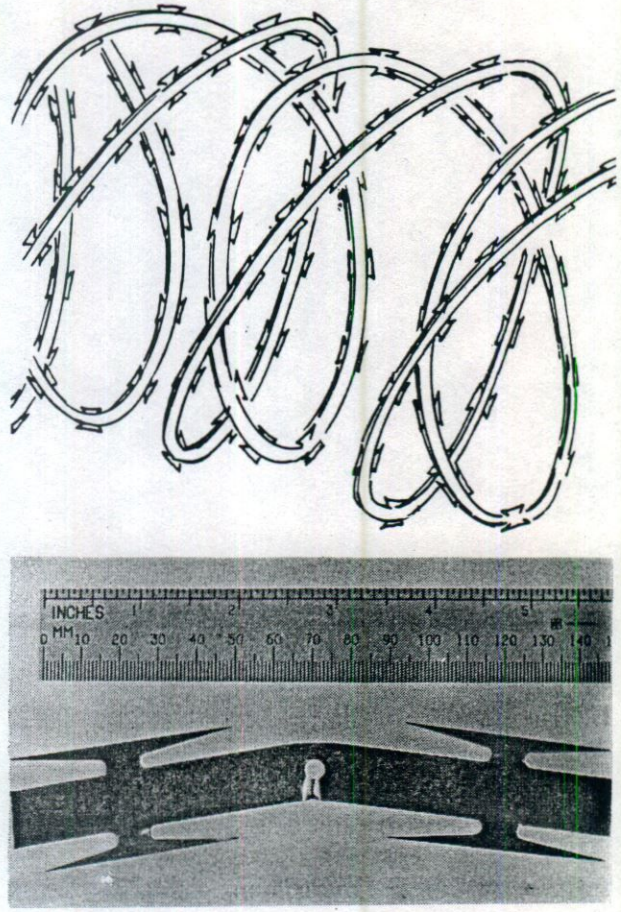

Figure 3-3. General Purpose Barbed Tape Obstacle (GPBTO) Type II. Est. Cost: $3.10/ft ($10.20/m) [FY 79].

Type I GPBTO

Type I GPBTO is a military version used in establishing perimeter barriers in the field. It consists of seven double-coiled assemblies of blackened barbed tape and seven polystyrene barbed tape dispensers. Anchors (metal tent pins) are supplied for attachment to the surface. Because of its neutral finish, Type I GPBTO reflects less light than Types II or III and is ideally suited to military operations. Since Type I is intended for a quick set-up of short duration, as in military movements during wartime, it does not have to be constructed of long-life materials.

Type II GPBTO

Type II GPBTO is a matt-finish stainless steel version of Type I GPBTO, which forms a double spiral, one spiral inside the other (one with a left-hand lead and the other with a right-hand lead). The coils are free standing due to the use of stainless steel spacer wires. When fully extended, its length is 66 feet and its spiral diameter is approximately 30 inches. Type II GPBTO is supplied with stainless steel wire ties and anchors (metal tent pins). A recovery tool is available to allow the Type II GPBTO to be reused.

Type II can be used on or near fences and walls as an enhancement or for the construction of separate barriers. Since Type II GPBTO is fabricated from stainless steel, it is ideally suited for fixed-site installations where climate or local weather conditions would have little effect on it. Besides being attached as a fence topping, it can also be attached either to the inside or outside (on double fence) surface of chain-link mesh fabric with stainless steel wire ties.

If Type II GPBTO is installed horizontally on the ground, it can be staked every 22 feet with the three anchors supplied with each roll of barbed tape. Additional anchors should be used in windswept areas at a recommended distance of 5 feet. One problem associated with GPBTO (and also with BWC and BTC) is trash accumulation. When paper, weeds, leaves, etc., are caught in the barbed tape, a method should be devised to remove the trash, if for no other than esthetic reasons. In addition, grass and weeds can intertwine themselves in the barbed tape, thereby reducing its delay effectiveness. This condition can be remedied by the use of a soil sterilant or pavement.[6] Costs for sterilants range from $0.10 a square yard for a chemical penetration treatment to $6 a square yard for 2-inch-thick Gunite on level surface. Life expectancies for such treatments range from 2 to 20 years. A defoliant agent, if acceptable, can also be used to kill existing growth and prevent future growth.

Type III GPBTO

Type III GPBTO is a single, 18-inch-diameter coil of stainless steel barbed tape which is used primarily as a fence or wall topping around fixed sites. Each Type III coiled assembly comes with stainless steel wire ties for attachment to chain-link fences or walls. Besides being attached directly to the top of the chain-link fabric, Type III GPBTO can also be supported and tied to a single wire (12-gauge) strung on outriggers facing toward the inside of the fence. This method spaces the barbed tape evenly, prevents movement of the barbed tape, and supports the barbed tape from an inaccessible location. When the outriggers face toward the inside, the solid handhold that can be used by outsiders for climb-overs is eliminated.

Conclusions

GPBTO is a vast improvement over barbed wire. Besides having a vicious array of barbs, it also takes up less volume, takes less time to erect, and is more effective in keeping intruders from climbing or walking through perimeter fences or barriers. The amount of delay that is desired at perimeter fences or barriers must be considered in relation to the complex arrangement and cost of the materials used.

ENHANCED STANDARD FENCES

Placing rolls of barbed tape on or near standard fences can moderately enhance their capability to delay intruders. Arrangements are limited only by land availability and funds for upgrading.

Attaching one roll of barbed tape to the outriggers of an existing perimeter security fence, as illustrated in Figure 3-4, is probably the most cost-effective addition that can be made since an intruder must now bring additional aids or bulky equipment to climb over the fence.[7] GPBTO can be tied to the chain-link fabric and the existing barbed wire by means of stainless steel wire ties. Reversing the outriggers to point from outside to inside when installing BTC or GPBTO as a fence topping eliminates the handgrip used by outsiders in climb-overs. Also, if the top rail on a GPBTO or BTC-topped fence is eliminated, the fence fabric becomes loose and flexible and consequently is much harder to climb. However, if vibration-type sensors are used on a fence, the top rail should be retained since it limits excessive fence fabric movement, a cause of increased false alarms during windy weather.

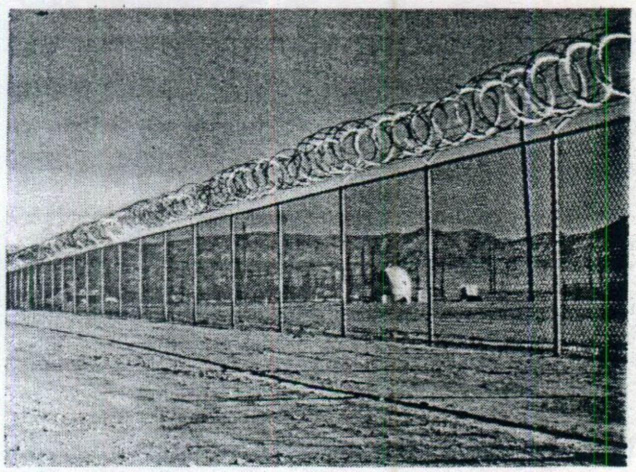

Figure 3-4. Alternate Security Fence with Single Roll 30/24 GPBTO. Upgrade Cost: $5/ft ($16/m) [FY 79].

Other enhancement possibilities are the placement of barbed tape either horizontally on the ground or against the chain-link fabric. Figures 3-5 and 3-6 show these installations. When the rolls are placed vertically, the bottom row should be staked to the ground with anchors (metal tent pins). The barbed tapes can be placed on either side of the chain-link fabric. Usually the barbed tapes are placed on the inside of an outside perimeter fence and on the outside of an inner (double) fence (Figure 3-7). This prevents accidental injury to the casual passerby, both outside and inside a site or facility. When rolls of barbed tape are placed horizontally, they are staked to the ground. Care must be taken to prevent excessive plant growth, and methods should be devised for removal of windblown trash. Even when perimeter fences are enhanced with numerous rolls of BTC or GPBTO, climb-overs, crawl-unders, and cut-throughs are possible with simple breaching aids, as indicated in the section, "Penetration Methods and Tools."

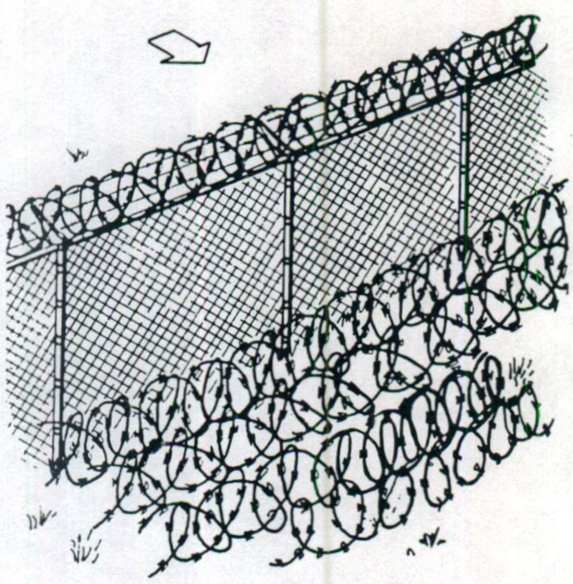

Figure 3-6. Standard Fence with Five Rolls 30/24 GPBTO. Up-grade Cost: $30/ft ($98/m) [FY 79].

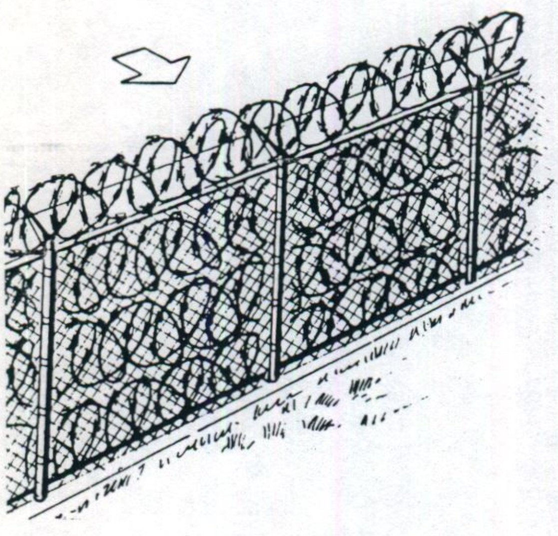

Figure 3-5. Alternate Security Fence with Four Rolls 30/24 GPBTO. Upgrade Cost: $20/ft ($66/m) [FY 79].

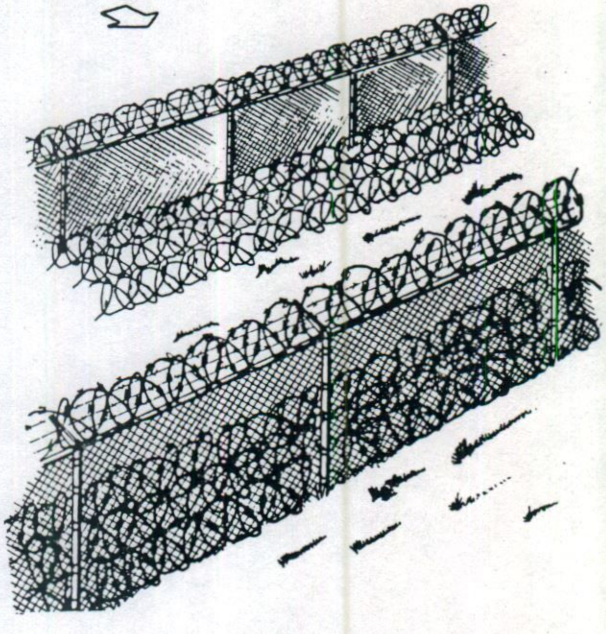

Figure 3-7. Standard Double Fence with Eight Rolls 30/24 GPBTO. Upgrade Cost: $50/ft ($164/m) [FY 79].

ADVANCED PERIMETER BARRIERS

Several advanced perimeter barrier prototypes have been designed to extend the delay time near the perimeter of a fixed site. All of these barriers use barbed tapes as a principal deterrent. Construction details and penetration delay times for these barrier prototypes* are discussed in the following paragraphs.

Horizontal Rows

Ten rows of Type II GPBTO are used to form a barrier 30 inches high and 25 feet wide, as depicted in Figure 3-8. Since a roll of GPBTO is only 66 feet long, small T-posts must be used to splice subsequent rolls together. The splices are staggered so as not to form a vulnerable path leading from front to back. In addition, all inner rolls are staked to the ground at least every 20 feet, and end rolls are similarly staked every 5 feet. Plant growth and windblown trash accumulation should be considered before erecting this perimeter barrier.

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Figure 3-8. Ten Horizontal Rows GPBTO. Est. Cost: $40/ft ($130/m) [FY 79].

Three Mounds

Three mounds, each with six rolls of BTC, are used to form a barrier 6.5 feet high and 27 feet wide. Figure 3-9 shows this installation. Since each roll of BTC is only 50 feet long, subsequent rolls are spliced together at random intervals. To help support each mound of BTC, 8-foot-long T-posts are used every 6 feet. Each roll of BTC is wired to the post. The seven inner/bottom rolls are staked to the ground at 12-foot intervals. Both end rolls are staked every 6 feet. Plant growth and windblown trash accumulation are two problems to be considered in conjunction with the use of this barrier.

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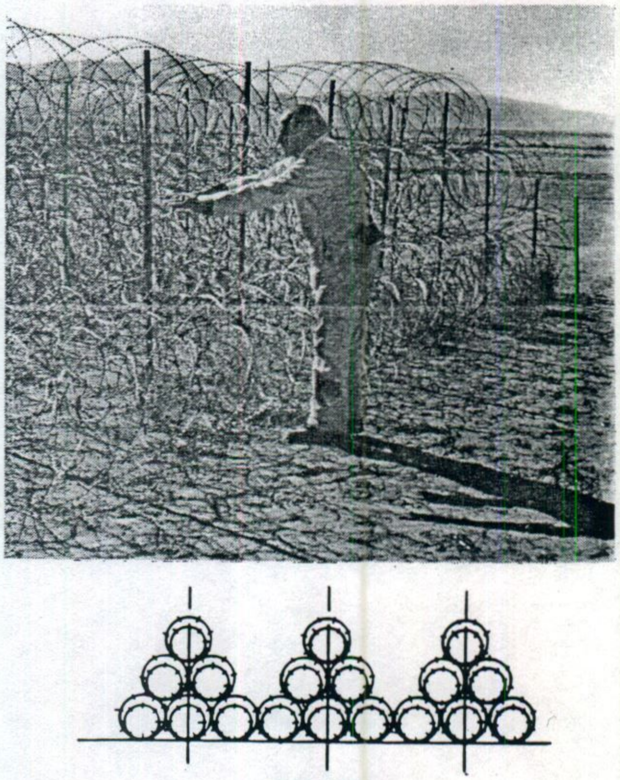

Figure 3-9. Three Mounds with 18 Rolls BTC. Cost: $34/ft ($110/m) [FY 79].

V-Fence (Personnel)

The personnel V-fence consists of 2.875-inch-diameter posts set at an angle of 60° in 30-inch-diameter by 24-inch-high concrete footers, which are placed 12 inches below grade. The posts are on 10-foot centers and staggered 5 feet, front to back. The chain-link mesh is 10 feet high with a cable installed at the top.

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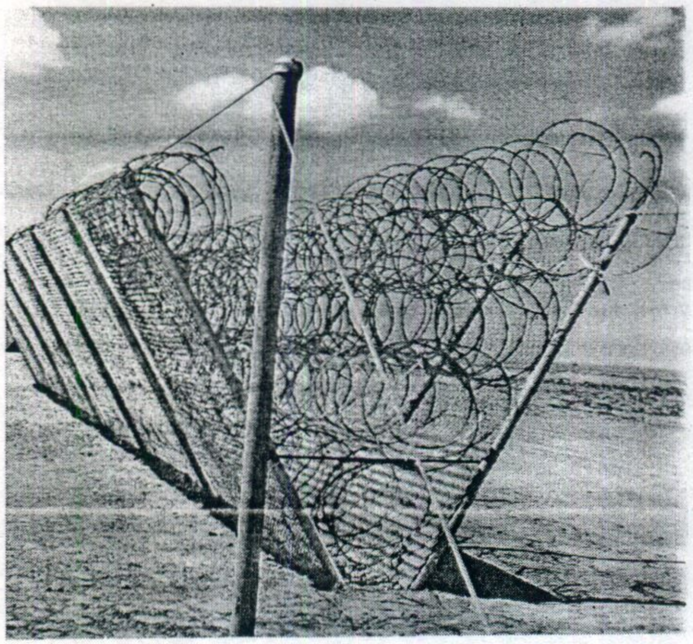

Figure 3-10. V-Fence with Eight Rolls GPBTO. Est. Cost: $89/ft ($292/m) [FY 79].

V-Fence (Personnel/Vehicle)

The personnel/vehicle V-fence is constructed from the same materials as the personnel V-fence except that another corrugated steel sheet is attached to the inside post to form a V-shaped trough.

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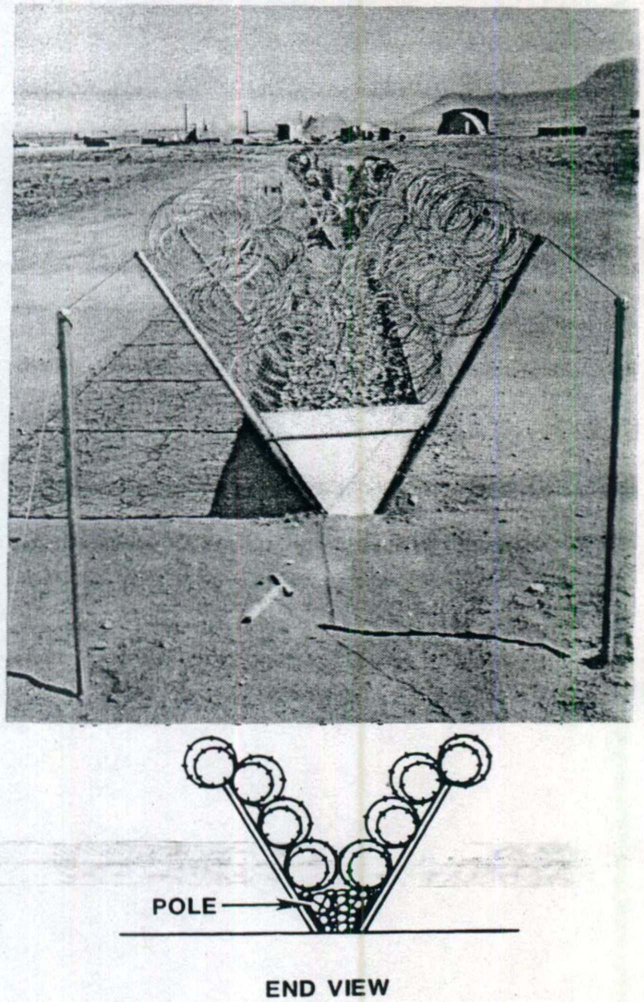

Figure 3-11. Personnel/Vehicle V-Fence with Eight Rolls BTC. Est. Cost: $97/ft ($318/m) [FY 79].

Lethal Barriers

A number of lethal systems have been considered for possible use as perimeter barriers. Two such systems examined are electrified fences and mine fields. Many problems are involved in the installation, maintenance, safety, and legality of lethal systems.

Electrified Fence

Lethal high-voltage fences are usually installed around highly sensitive secured sites. The fence fabric is positioned above grade to prevent grounding the fence, and vertical line posts are usually mounted on insulators imbedded in a concrete footer or sill. A typical high-voltage fence has a maximum current load of 100 amperes at 7200 volts. Maintenance of electrified fences is usually very costly. Excessive false alarms are experienced during rainy weather, and grounding of the fence due to wind blown trash or plant growth is a constant problem. Additional security forces are required to patrol grounded sections of the fence, and backup generators are required to maintain the fences in case of a commercial power outage.

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Minefields

Minefields could be used as active perimeter barriers around specific sensitive sites.[9] Both aboveground and belowground mines can be used in a minefield system. Effective use of minefields imposes a number of requirements. Effective belowground mining of a site with antipersonnel mines usually requires a large amount of land. In addition, to assure high reliability of detonation during penetration attempts, a large number of antipersonnel mines must be deployed; maintenance is proportionately high.

Aboveground mines such as the mini-Claymore mine can also be used to mine an area. The Claymore mine, a directional fragmentation mine, can be mounted on walls, fences, or posts.

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Adverse weather conditions, such as winter conditions or tropical climates, can affect both aboveground and belowground mines. Mines covered with 4 to 10 inches of snow and mines with frozen fuses become ineffective. In tropical climates, fuses and explosive components deteriorate rapidly.

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PENETRATION METHODS AND TOOLS

Methods of personnel penetration of fences vary and include breaching aids such as gloves, hand tools, ladders, bridging materials, and explosives. Rapid entry or exit is possible for most existing fences and perimeter barriers, as indicated in Figures 3-12, 3-13 and 3-14. Employment of stepladders and other bridging methods can be used to bypass fence disturbance sensors and may not leave evidence of entry or exit. Explosives will likely generate an alarm, but cutting a fence with hand tools may not be noticed for some time. Helicopters, balloons, parachutes, and gliders can circumvent the most elaborate perimeter barriers to land in side an area without significant delay.

VEHICLE BARRIERS

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All barriers can eventually be breached if the adversary is allowed enough equipment and left unopposed for enough time. Therefore, a vehicle barrier should be designed so that it cannot be readily breached by ramming with a vehicle and so that the time required to breach the barrier

Figure 3-12. Time Required To Go through Fences and Perimeter Barriers

Figure 3-13. Time Required To Go under Fences and Perimeter Barriers

Figure 3-14. Time Required To Go over Fences and Perimeter Barriers with breaching (or bridging) aids adequately delays the adversary until other physical protection system elements can respond.

Earthen Barriers and Excavations

Vehicle barriers can be designed to use existing dirt, rock, sand, and similiar materials. Triangular ditches can be cut into the earth to prevent vehicles on low-angle approaches from penetrating a facility (Figure 3-15). These triangular ditches should be about 13 to 20 feet wide and 5 feet deep, depending on the slope of the terrain.[10] Facing the cut with revetment material prevents erosion. Revetment materials include rock, concrete, blocks, or a combination of materials.

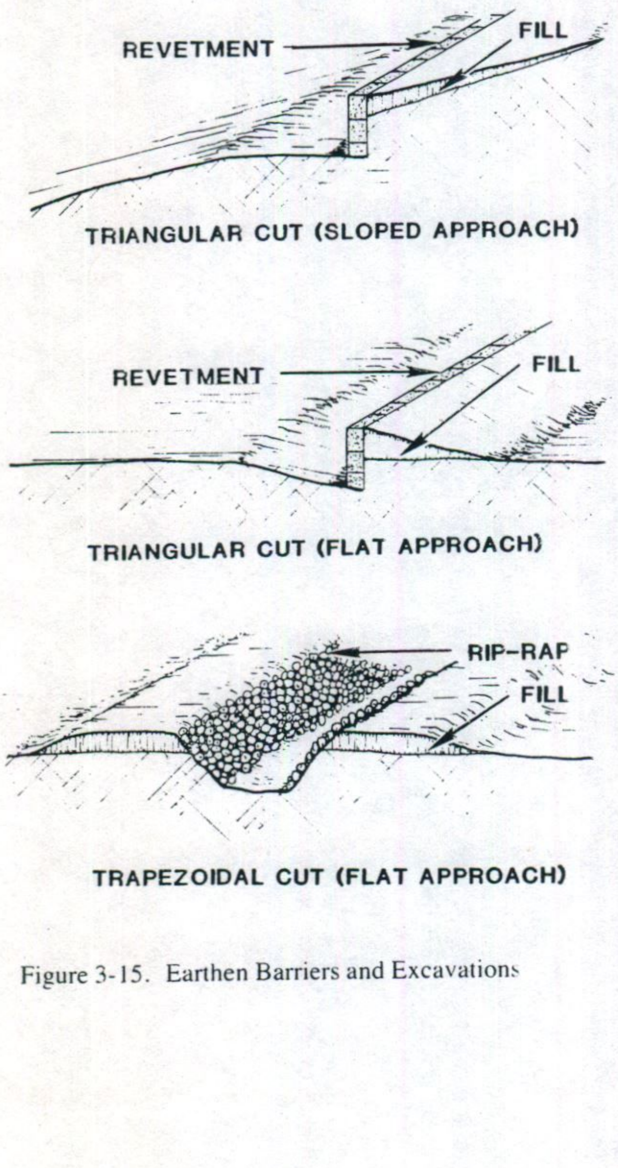

Figure 3-15. Earthen Barriers and Excavations

In addition to triangular cuts, trapezoidal ditches can also be constructed (also shown in Figure 3-15). If the ditch is properly designed, it can prevent vehicular penetration from either side. Trapezoidal ditches are typically about 13 feet wide at the top, 7 to 10 feet wide at the bottom, and 5 feet deep.[10] Revetting is recommended.

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Concrete Barriers

Concrete barriers can be made in a variety of shapes and sizes. A basic concrete cube with 4-foot sides, a concrete cylinder 4 feet in diameter and 4 feet high, or a concrete tetrahedron 4 feet high with a 5-foot-square base could all be used as vehicle barriers.[10] Most of these obstacles could be cast in place and anchored to the ground so that removal, even with a large forklift, would be difficult. Explosives can be used to destroy most concrete blocks; however, this would consume time, which is the intent of the barrier. For additional information concerning the use of explosives against concrete, see Chapter 4: "Walls."

A concrete highway median barrier (Figure 3-16) can also be used around a fixed site as a perimeter vehicle barrier. Commonly referred to as the "New Jersey Bounce," it was first used along the turnpikes in New Jersey as a median barrier to prevent head-on collisions. The barrier is approximately 32 inches high, 24 inches wide at the base, and 6 inches thick at the top. The barrier can be erected from either precast tongue and groove sections or can be cast in place with special concrete-forming equipment.

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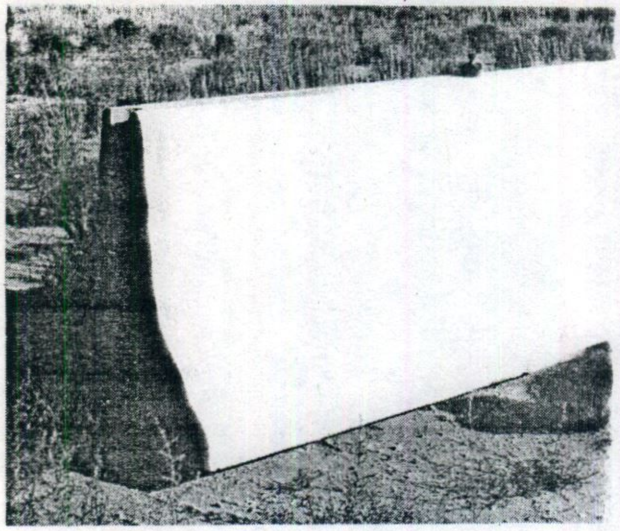

Figure 3-16. Concrete Highway Median. Est. Cost: $25 to $32/ft ($82 to $105/m) [FY 79].

Metal Guardrails

Standard highway guardrails or median barriers, such as the examples shown in Figure 3-17, can be used as perimeter vehicle barriers. Although not designed to prevent head-on penetration, a cable, W-beam, or box beam guardrail[11] could immobilize a light weight vehicle attempting a crash-through intrusion. A cable guardrail consists of S-beams spaced on 16-foot centers with three ¾-inch-diameter steel cables spaced 3 inches apart. Total height is approximately 27 inches. A W-beam guardrail consists of S-beams spaced on 12.5-foot centers with steel"W" sections bolted to the S-beams. A wider, corrugated W-beam, known as a Thrie beam,[12] could be used in place of the standard double-corrugated W-beam. Total height is 27 to 30 inches for the standard W-beam and 32 inches for the Thrie beam. A box beam guardrail or median barrier consists of S-beams spaced on 4- to 6-foot centers with either a 6- by 6-inch or 6- by 8-inch steel tube used as the beam. Total height for the box beam rail is 27 inches. Wood posts are commonly used instead of the steel S-beams, but maintenance is increased due to material deterioration.

Most highway barriers are designed to be effective at small impact angles (less than 30°). Complete vehicular penetration of most highway guardrails or median barriers can be made with a light vehicle; however, damage to the vechicle may be extensive and the occupants could be injured. Explosives or bridging can also be used to aid in penetrating standard vehicle barriers.

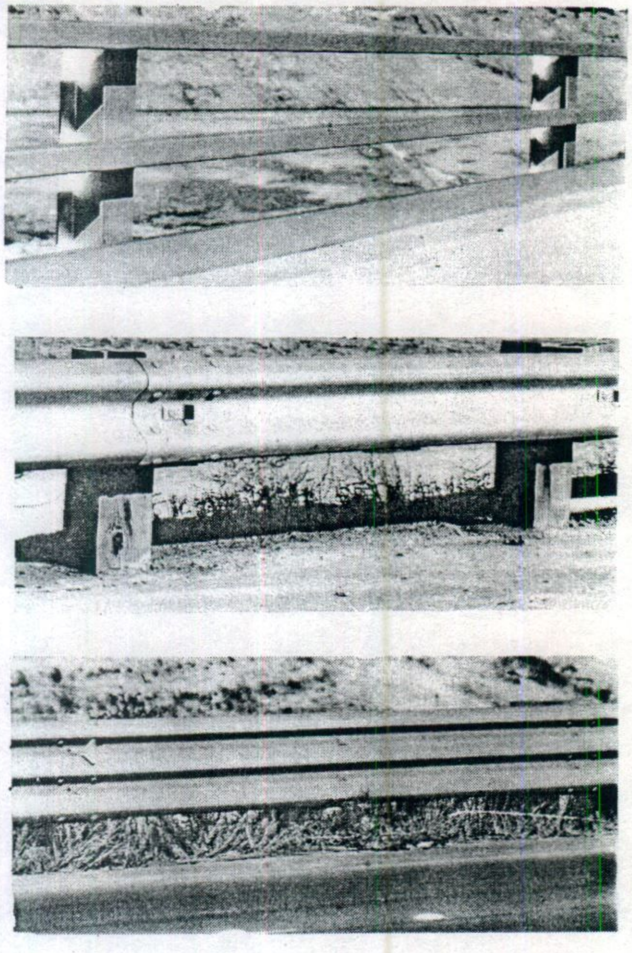

Figure 3-17. Metal Guardrails. Est. Cost: $5 to $18/ft ($16 to $59/m)

Advanced Vehicle Barriers

A number of advanced perimeter barrier designs have been tested for penetration by a light vehicle (4000 pounds maximum). Tests were conducted at Sandia National Laboratories using ¾-ton trucks, which impacted the barriers at approximately 50 mi/h. The basic goals in a vehicle barrier are to (1) provide a barrier that can absorb, without full penetration, the kinetic energy of a moving vehicle or (2) attain needed delay time before defeat or bridging of the delay feature can be accomplished. Results of the vehicle tests are listed in Table 3-1 and some detailed printouts are compiled in the data base tables of Chapter 15: "Penetration Rates and Data Base."

TABLE 3-1
Light Vehicle Penetration of Barriers

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Cable

A number of different methods have been tested to prevent light vehicles from crashing through a standard chain-link fence. One method of prevention is to place a ¾-inch or larger diameter aircraft cable in front of the vertical line post but in back of the chain-link mesh fabric (see Figure 3-18). The cable is fastened to each post with a U-clamp at a height of about 30 inches and is periodically anchored. However, even though the cable can be effective in stopping a light vehicle, it can probably be penetrated with a larger vehicle or quickly cut with hand or thermal tools. Multiple or larger diameter cables would be required for larger vehicles. If this type of vehicle barrier, i.e., outer perimeter fence, is accessible to the intruder before an alarm is encountered, the cable could be covertly cut.

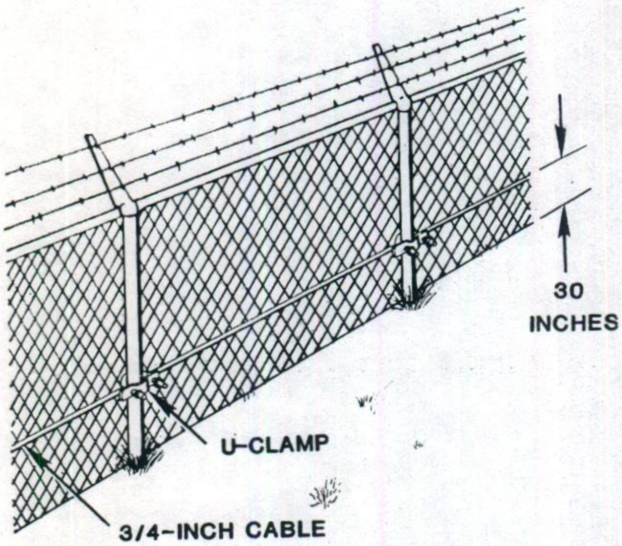

Figure 3-18. Cable. Upgrade Cost: $3 to $5/ft ($10 to $16/m) [FY 79].

Tires

A very simple but effective vehicle barrier can be constructed from used heavy-equipment tires. The tires, approximately 7 to 8 feet in diameter, are half-buried in the ground. Figure 3-19 illustrates this technique. The earth is tamped around the tires to hold them rigid. During a test, a light vehicle driven into these tires was not only stopped abruptly but was thrown backwards for a short distance. This test produced major vehicle damage and indicated that any occupant of the vehicle would have been severely injured. Large trucks might be able to penetrate this barrier; however, the risk that the vehicle will roll is high. The use of explosives (5 to 10 pounds of composition C-4) to open a hole through this vehicle barrier proved ineffective.

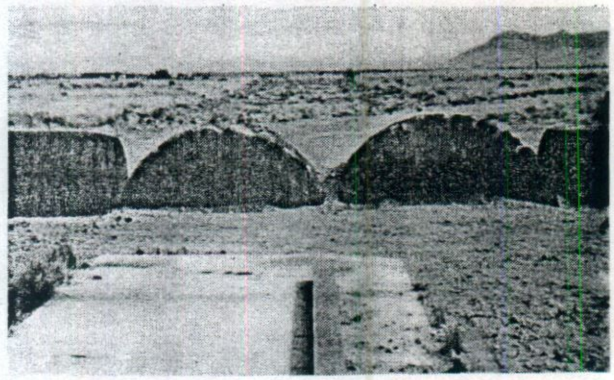

Figure 3-19. Heavy Equipment Tires. Est. Cost: $5 to $8/ft ($16 to $26/m) [FY 79].

Personnel/Vehicle V-Fence

One perimeter barrier which is designed to prevent both personnel and vehicles from entering a site or facility is a dual chain-link fence set at 60° angles to form a "V." Figure 3-11 (see the subsection, "V-Fence Personnel/Vehicle") shows an example of this barrier. When attached to the inside surface, corrugated sheet steel forms a V-shaped trough 30 inches above ground and 12 inches below ground. The trough is partially filled with 2- to 5-inch rock, and a telephone pole (nominal 9-inch diameter) is placed on the rock. Six rolls of GPBTO or BTC, which are attached to the mesh fabric, complete the barrier.

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Angled Posts

A formidable vehicle barrier can be constructed of metal posts (2-inch nominal) or railroad rails partially embedded below ground in concrete pillars. The posts are angled outward (toward intrusion vehicles) at a 30° to 45° angle and are spaced approximately 4 feet apart. Any vehicle which tries to penetrate this barrier at high speed would suffer major damage, and any occupants would be severely injured.

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Railcar Barriers

Railroad tracks that enter a secured area provide a convenient entry point through which an unauthorized locomotive or railcar can easily pass. This kind of penetration can be prevented in a number of ways. For example, a split point or hinged derail could be used to cause a moving locomotive or railcar to run off the rails. Also, a loaded railcar with its brakes set and locked could be placed on the rail line to slow down or stop a moving locomotive or railcar attempting penetration. Wheel chocks can also be used to hold the loaded railcar in place. A track switch (turnout) outside of the outer security fence could be used to turn a moving locomotive or railcar onto a side track; however, care must be taken to secure and monitor any rail switch so that an adversary cannot change rail direction. A moving locomotive or railcar is extremely hard to stop and, unless the car strikes a massive object or is derailed or detoured, penetration is likely.

Vehicle Penetration Methods

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Conclusions

Barbed tapes can be used as enhancements to upgrade existing perimeter fences and prevent adversaries not equipped with breaching aids from rapidly entering a site.

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Bridging methods require that the adversary transport the bridging materials to the perimeter and then cross over it, both highly visible actions. Some breaching methods are also highly visible. Any actions which require the adversary to engage in highly visible activity increase the probability that the adversary will be detected and present the guards, if nearby, with a more accessible target if firepower is used.

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Plant growth, windblown trash, and snow can reduce the effectiveness of a barbed fence array. In addition, consideration must be given to the fact that perimeter barriers may be used by an adversary for firing positions or concealment.

When designing a perimeter protection system that includes intrusion detection sensors, CCTV assessment, lighting, and any type of personnel or vehicle barrier, extreme care must be used in the physical layout to assure complete functional compatibility of all the elements.

GATES

Introduction

Gates establish specific points of entrance and exit to an area defined by fences and walls. They function to limit or prohibit the free flow of pedestrian or vehicular traffic and establish a controlled traffic pattern.

Existing Gates

Gate barriers contiguous with the perimeter fences should be equal in effectiveness to the fences in order to function as equivalent barriers. Gates often require additional hardening features since, as a consequence of their weak hardware accessories and the fact that a vehicular driveway is aimed directly toward them, they are usually considered easy to defeat.

Chain-link fabric gates are those in most general use throughout government installations. Federal specifications have been written for chain-link fence and gate materials and have been approved by the Commissioner, Federal Supply Service, General Services Administration, for use by all Federal agencies.[13] Installation specifications are reasonably uniform throughout the construction industry due to the fact that the manufacturers of chain-link fencing materials have formed an institute to promote research and to police the quality of their products.[14] This institute has published a recommended set of specifications that has been generally adopted, with slight modifications, by member manufacturers.

The usual height of most perimeter gates is 8 feet plus an additional 1 foot for the barbed wire outriggers. Pedestrian gates are normally 3 to 6 feet in width with their supporting hardware designed to accommodate the weight of the frame, fabric, and locking mechanism. Vehicular gates may vary in width from 8 feet to a virtually unlimited size; however, most vehicular gates over 15 feet in width require overhead guy cables or rollers to support their weight. Consequently, vehicular gates must have larger, stronger, and more durable hinges and frames.

Common types of gates are the swing and sliding gates. Variations of each include double- and single-leaf swing gates, overhead supported or cantilevered sliding gates, one-way sliding gates, and biparting gates. Any of these may be either pedestrian or vehicular gates, the only differentiation being their width and hardware requirements. The site plan will usually dictate which type of gate should be used.

The overhead lift gate (guillotine) is not widely used and is more expensive than swing or sliding gates. The advantage of using an overhead lift gate is that it allows a site plan so restricted that the only way to open it is upward. The standards for an overhead lift gate (see Figure 3-20) have been provided by the U.S. Steel Supply Division of U.S. Steel, Cyclone Fence, from their archives. They have had no need for this type of gate for approximately 30 years.

Turnstile (rotational) gates are designed exclusively for control of pedestrian traffic. They are manufactured in two heights: low and full. Low, waist high turnstiles (nominally 36 inches high) are used to handle crowds, count attendees, and collect admissions. These turnstiles must be constantly attended for complete control to be assured, and they afford little or no barrier constraints. The full-height turnstile, which completely surrounds a user as they pass through the gate, provides better security control since it cannot be readily bypassed, even if unattended (see Figure 3-21). Only this latter type of turnstile will be considered in this chapter. These are steel multibar, three-arm, security-type gates with rotating bars interleaved with fixed bars and spaced to prevent passage.

The widest use of turnstiles is at amusement parks, subway stations, and various industrial plants. These gates have many optional features which add to their versatility. Remote means can be used to record movement and to release the mechanism for travel in each direction and can be coupled with CCTV monitors and two-way voice communication systems. Chapter 10 of the *Entry-Control Systems Hand book*[15] discusses in detail these and other systems which have been designated for use in entry portals. In this context, turnstiles, appropriately hardened, could be used for traffic control and as barriers for perimeter (or building) entry control systems.[16]

Penetration

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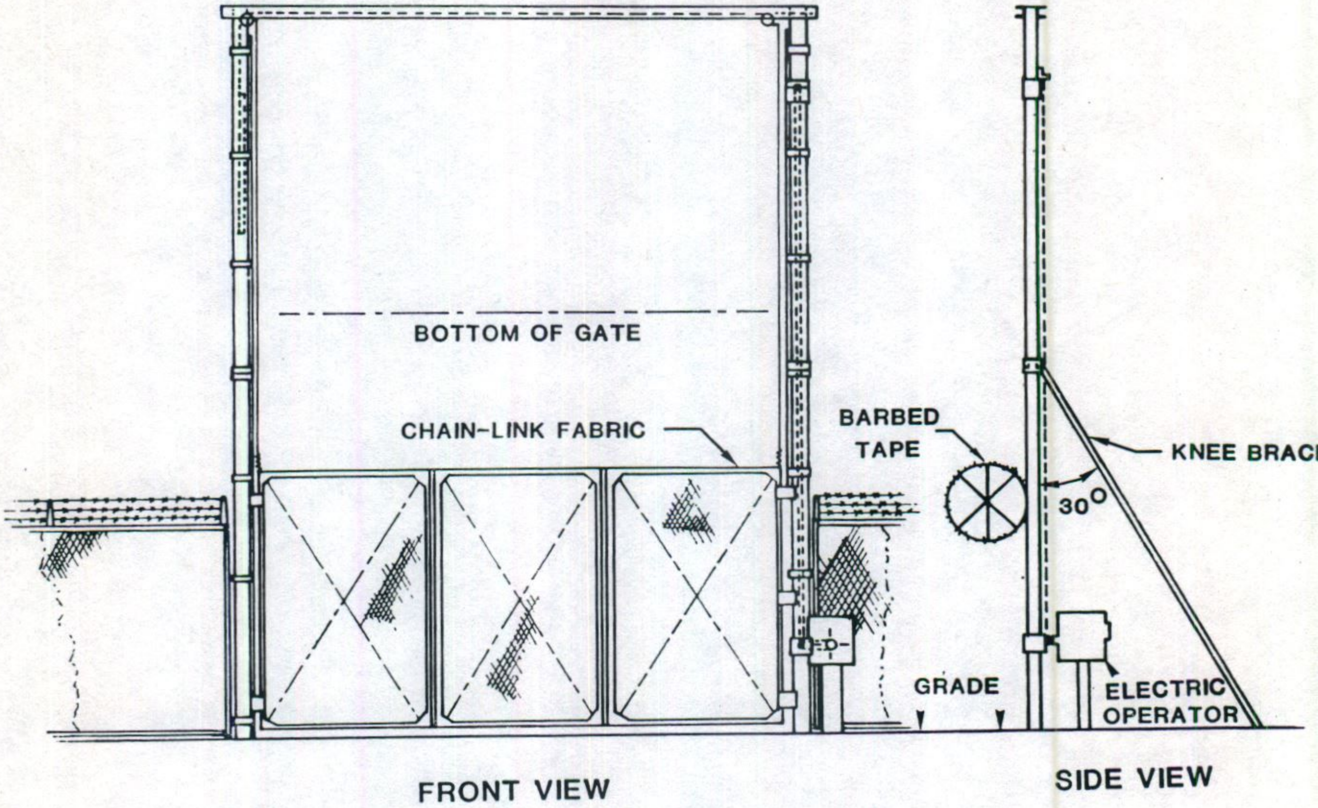

Figure 3-20. Overhead Lift Gate (Guillotine)

Swing Gates

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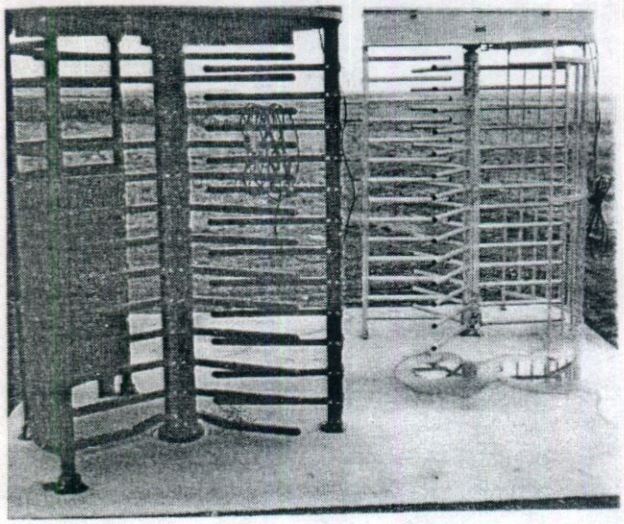

Figure 3-21. Typical Turnstile Gates — Full-Height

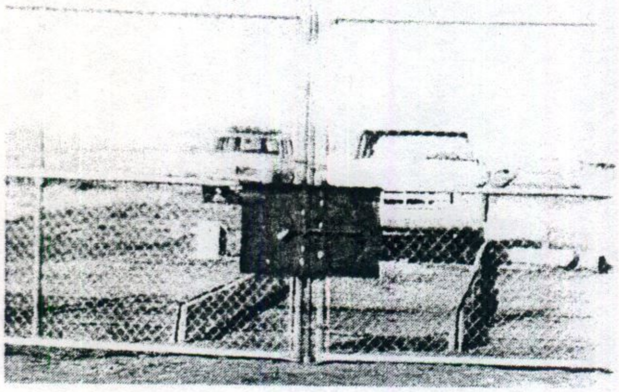

Figure 3-22. Pretest Configuration for Vehicle Penetration Test Using Double-Leaf Gate

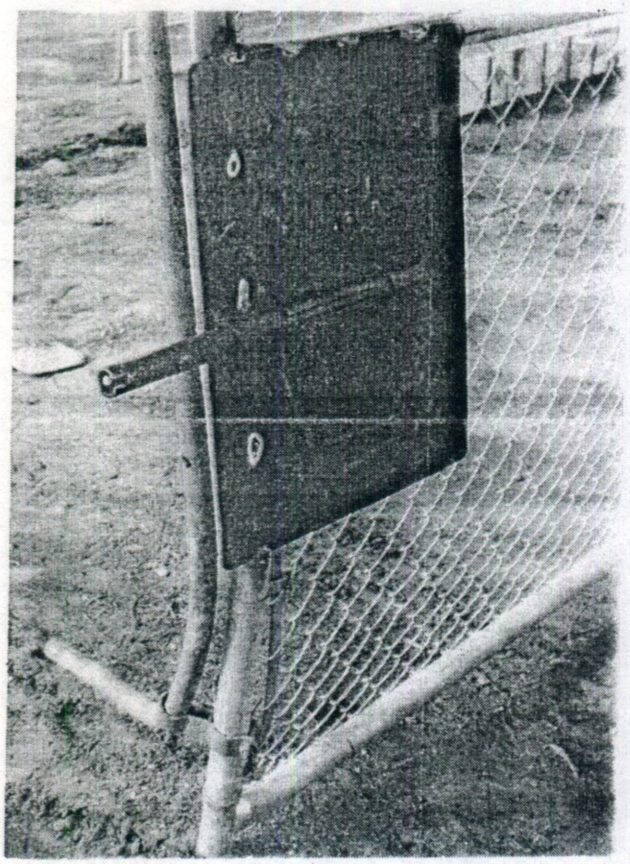

Figure 3-23. Post-Test Results of Vehicle Test on Single-Leaf Gate (Bolt still in Locked position, foot-bolt bent, and gate keeper still in locked position).

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Sliding Gates

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Lift Gates

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Turnstile Gates

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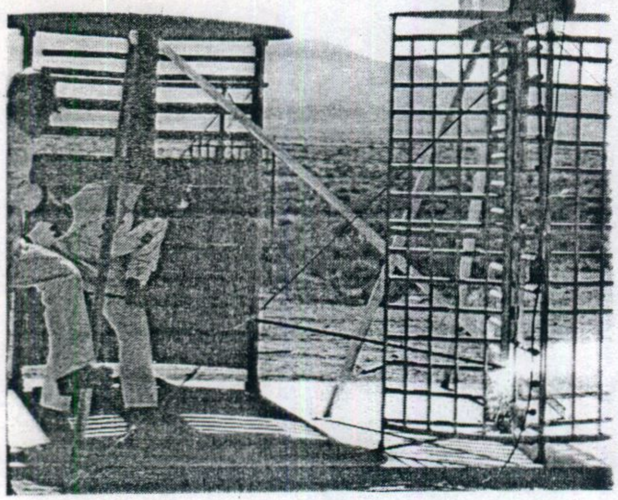

Figure 3-24. Burn Bar Attack on Light-Duty Turnstile

Enhancements

The orientation of vehicle gates and their driveways could reduce the probability of their being breached by vehicles. Driveways constructed with multiple turns on each side of the gateway with as small a turning radius as is consistent with the maximum length of any vehicle utilizing the gate will reduce the approach and departure speed of vehicles.

The concept of installing multiple hardened gates at the perimeter is an option for upgrading vehicle portals. These gates would be interlocked, requiring one gate to be closed and locked before the other could be released and opened. The area between the gates provides a holding area to allow sufficient time to determine if contraband materials or unauthorized personnel are attempting entry or exit.

Swing Gates

Pedestrian and vehicular swing gates are usually secured on the hinge side by only two hinge pins. Wide and heavy vehicular gates normally use ¾-inch-diameter pins fabricated from steel-bar stock about 4 inches long. Structural strength and penetration resistance can be improved by replacing the pin hinges with a base pivot which rotates around a long, solid steel rod set in concrete, running inside the pipe frame of the gate and passing through several guide brackets attached to the gate post. This multiplies the area of steel to be cut or forced by 4 to 6 times the present area, and also nullifies several methods of attack (see Figure 3-25).

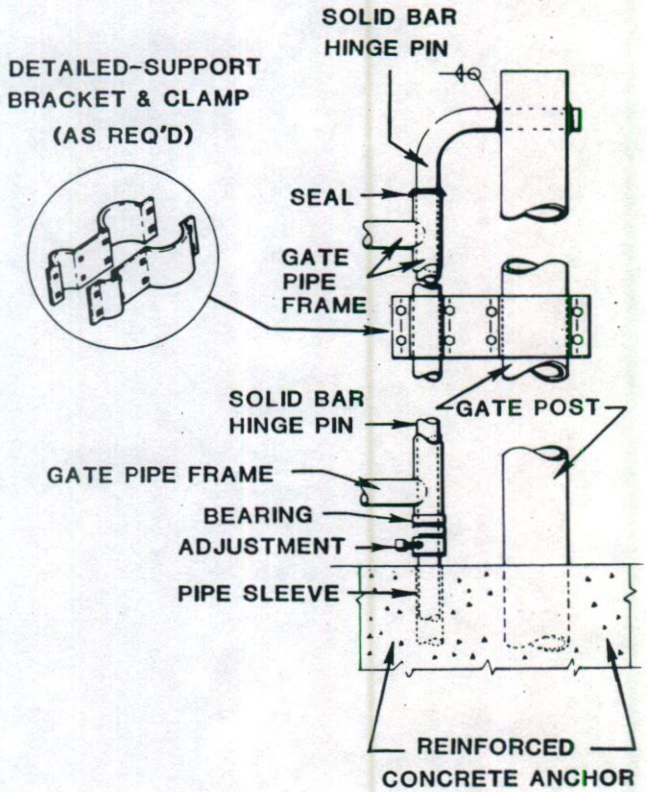

Figure 3-25. Gate Hinge Modifications

The present practice of using a single-point latch and bolt mechanism on pedestrian and vehicular swing gates could be modified to provide multiple latches or bolts, all working in unison for ease, efficiency, and added strength (see Figure 3-26). Double-swing gates currently have one leaf anchored at the central meeting point, with a single foot-bolt attached to the gate. This configuration may be improved by using two foot-bolts, each several feet long, which run inside the gate pipe frame and slide down into pipe sleeves, which are set in a large concrete block flush with the grade.

Vehicular swing gates may be reinforced by the addition of structural horizontal bars (I-beams, channels or angles back-to-back) welded into the gate frame at bumper and/or windshield height. These may be as large as feasible to balance the structural design of all gate components.

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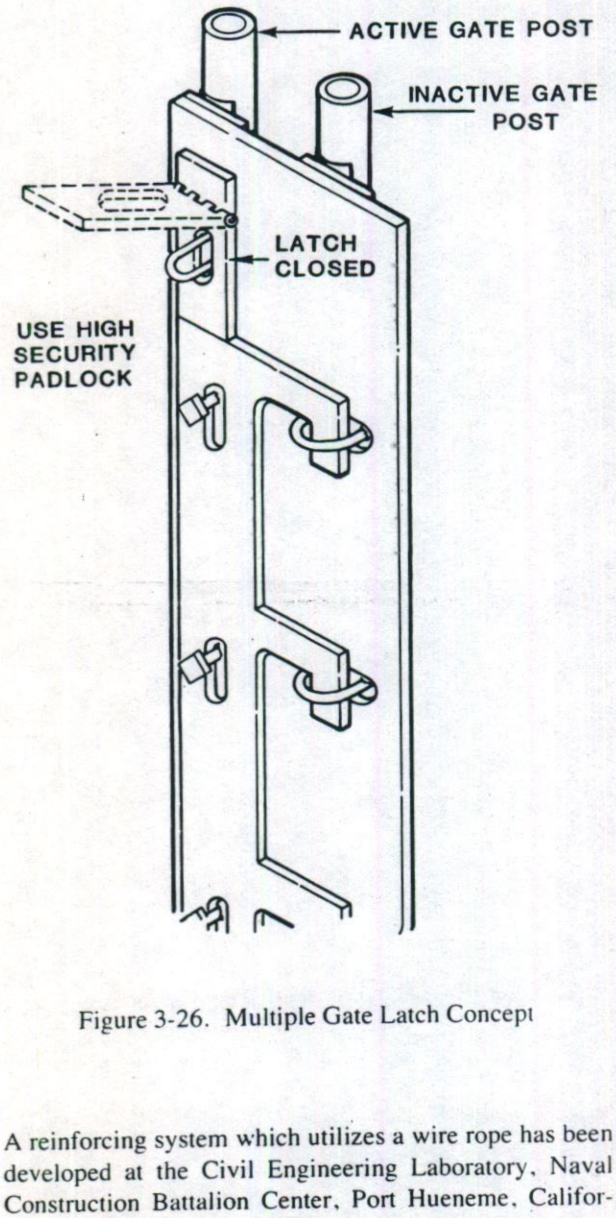

Figure 3-26. Multiple Gate Latch Concept

A reinforcing system which utilizes a wire rope has been developed at the Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, California, for double chain link gates. This wire rope is attached to a guyed concrete deadman structure located on each side of the gate. It runs from a looped interlock on each gate post to the center meeting post, where it is chained with a protected padlock.[17]

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Sliding and Overhead Gates

Sliding and overhead gates can be improved to resist vehicular assault by the installation of an additional gate post with strut bracing at each end of the gate opening. Pushing or knocking of gate frame from the rollers or guides forces the frame against these reinforced, heavy posts and necessitates bending the frame in order to achieve further penetration. Redesign of the frame may be carried as far as it is deemed feasible to achieve a balanced equilibrium of post-to-frame stability.

Turnstile Gates

To increase penetration delay, turnstiles can be upgraded by protecting the ratchet mechanism and the electric outlet box and by reinforcing the turnstile bar arms. The ratchet mechanism and electric outlet box can be protected with armor plate covers which are welded on or assembled with nonremovable bolts. Hollow bar arms can be upgraded by the insertion of tool-resistant bars or cables to resist cutting and the replacement of bolts with welds.

In security applications, all turnstiles should be designed with gate arms set for double closure of the entry passage so that either one arm on each array must be cut instead of just a single arm or three bars on the interleaved side (see Figure 3-27). This would increase penetration time by a factor of 2.

Turnstile gates should be upgraded to provide the same penetration delay as adjacent structures. If possible, turnstile gates should not be installed in locations where they are vulnerable to ramming by vehicles. Should this type of installation be necessary then the gates should be protected with vehicle barriers.

Advanced Concepts

Personnel or vehicular gate barriers required to deny penetration are virtually unattainable if the adversary is allowed sufficient equipment, materials, and time. Many of the concepts which have been considered have merit for delaying vehicles but are not appreciable to delaying pedestrians. Some of the concepts considered include massive blocks, drawbridges and ferries over pits and

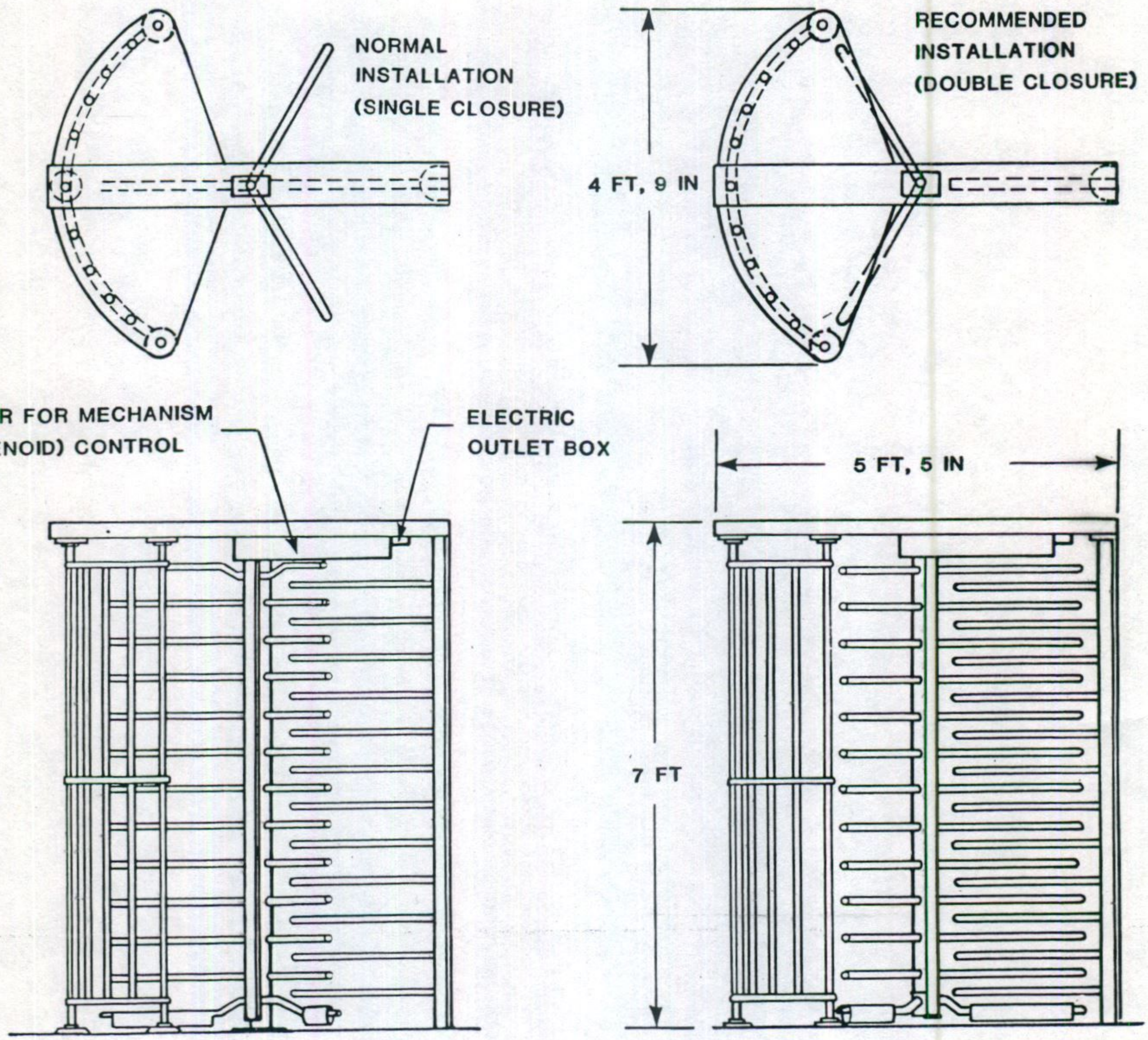

Figure 3-27. Turnstile (Rotational) Gate

moats, aircraft-type arrestors, safety nets such as those used at racetracks, and a combination tire-shredder (one-way exit device) and cattle guard. One of these ideas which may be developed to serve as a gate barrier for control of both pedestrian and vehicular traffic is the massive block.

Use of a massive reinforced concrete block as a gate barrier would establish an impressive and formidable obstacle which would deny access to most vehicles. [redacted] b3

[redacted] b3 This block may be of any configuration, but one option presently being considered is an 8-foot-square by 14-foot-long reinforced concrete block with personnel deterrents, such as arrays of barbed tape, imbedded or anchored in it to discourage individuals from climbing over it. Its full deadweight would rest on a smooth concrete slab; however, it could be moved aside with out a great expenditure of energy by the use of air pressure cushions, which would normally be turned off. This concept may be considered as "overkill" and consequently scaled down and altered as required.

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CHAPTER 4

WALLS

INTRODUCTION

This chapter discusses penetration evaluations of various wall configurations. Suggestions for possible modifications to increase the penetration resistance of walls are presented.

Walls of buildings, vaults, and other structures are usually considered to be more resistant to penetration and less desirable as targets for forcible entry than are doors, windows, vents, and other conventional wall openings. [redacted] b3

[redacted] b3 For purposes of wall penetration evaluation, it is assumed that a team of attackers will utilize the optimum tools and will be skilled in their use.

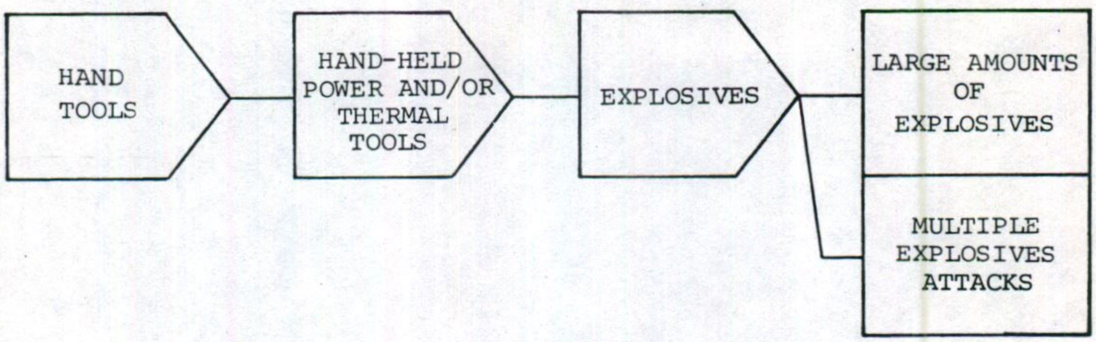

Figure 4-1. Escalation of Tools

The most common types of walls in existing facilities are

1. Reinforced concrete,
2. Expanded metal-concrete,
3. Concrete block,
4. Clay tile,
5. Precast concrete tee sections,
6. Corrugated asbestos,
7. Sheet metal, and
8. Wood frame.

The text includes a discussion of most wall configurations with graphs to illustrate comparative penetration times for various classes of tools, different wall constructions, and the effects of upgrading or modifications on penetration times.

A limited number of advanced wall concepts for new structures are presented.

Specific wall barriers and penetration tools and times are listed in Chapter 15: "Rates and Data Base."

REINFORCED CONCRETE WALLS

Reinforced concrete walls are commonly used in structures related to the storage and protection of sensitive materials. Because of their structural reputation and rugged appearance, concrete walls are almost universally believed to be formidable barriers.

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In conventional construction, strength and thickness of concrete and size and spacing of reinforcing materials are determined from structural requirements. There are a large number of possible combinations of concrete thicknesses and strengths and sizes and spacing of reinforcing bars (rebars). It is impractical to test all configurations. Therefore, for purposes of penetration evaluation, it is often necessary to interpolate or extrapolate the desired data from wall cross sections which have already been tested and analyzed.

Standard 28-day-cure concrete strengths range from 2500 to 6000 psi.[1] Rebar sizes are often shown as numbers, e.g., No. 3. The numbers represent multiples of ⅛-inch diameter, i.e., No. 3 is a ⅜-inch-diameter reinforcing bar. Concrete reinforcing varies from 6- by 6-inch 12-gauge mesh to No. 18 (2¼-inch-diameter) rebar.[2]

The costs of reinforced concrete walls vary considerably, depending upon locale, wall thickness, and design requirements. For purposes of comparison, a 12-inch-thick, 5000-psi concrete wall with two layers of No. 6 rebar at 6-inch centers will be used as the standard in this chapter. The cost of this wall, completely installed, is approximately $25 per square foot (Albuquerque, New Mexico, FY79).

Concrete has good mechanical properties in compression but little strength in tension and flexure. Tensile and flexural strengths are approximately 10 percent and 20 percent, respectively, of the value for compressive strength. Steel reinforcing resists the tensile and flexural loading.

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Two or more reinforced concrete walls used in series provide longer penetration delay times than one wall with a thickness equal to their combined thicknesses. The walls should be separated by several feet (such as a natural hallway or room). Penetration of multiple walls requires multiple individual efforts and the transport of tools through preceding walls. If explosives are used, retreat and return times are additive. There is also the possibility that contained internal pressure from the explosive charge will collapse the roof and/or surrounding structures, thus presenting further barriers in the form of rubble.

Reinforcement can be employed to extend the penetration delay time in most designs. Even though the concrete is penetrated by the explosion, the reinforcing material usually remains intact to the extent that it must be removed before entry can be accomplished. Removing the rebar often requires more time than is needed to remove the concrete. Therefore, using additional rebar, increasing rebar size, or decreasing center-to-center rebar spacing can be advantageous.

Grades of reinforcing steel range from 40 to 75 ksi. Sandia has tested only walls with 40-ksi steel.

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Four-Inch-Thick Concrete Walls

Four-inch-thick reinforced concrete walls are common but are not considered to be structural or load bearing. They are used as curtain walls to enclose the space between load-bearing structures such as columns.

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Figure 4-2. Penetration of 4-Inch-Thick Concrete Walls

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Figure 4-3. Penetration of 4-Inch-Thick Concrete Walls

Eight-Inch-Thick Concrete Walls

Eight-inch-thick reinforced concrete walls are structural and load bearing and are commonly found in all types of structures.

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Twelve-Inch-Thick Concrete Walls

Twelve-inch-thick reinforced concrete walls are commonly used in vaults and structures which store and protect sensitive materials.

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Figure 4-4. Penetration of 8-Inch-Thick Concrete Walls

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Figure 4-5. Penetration of 12-Inch-Thick Concrete Walls

Thicker Concrete Walls

Thick concrete walls which have been heavily reinforced can provide significant increases in penetration delay.

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Eighteen-Inch-Thick Concrete Walls

A test penetration was made on an 18-inch-thick, 5000-psi concrete wall reinforced with three layers of No. 6 rebar on 6-inch centers.

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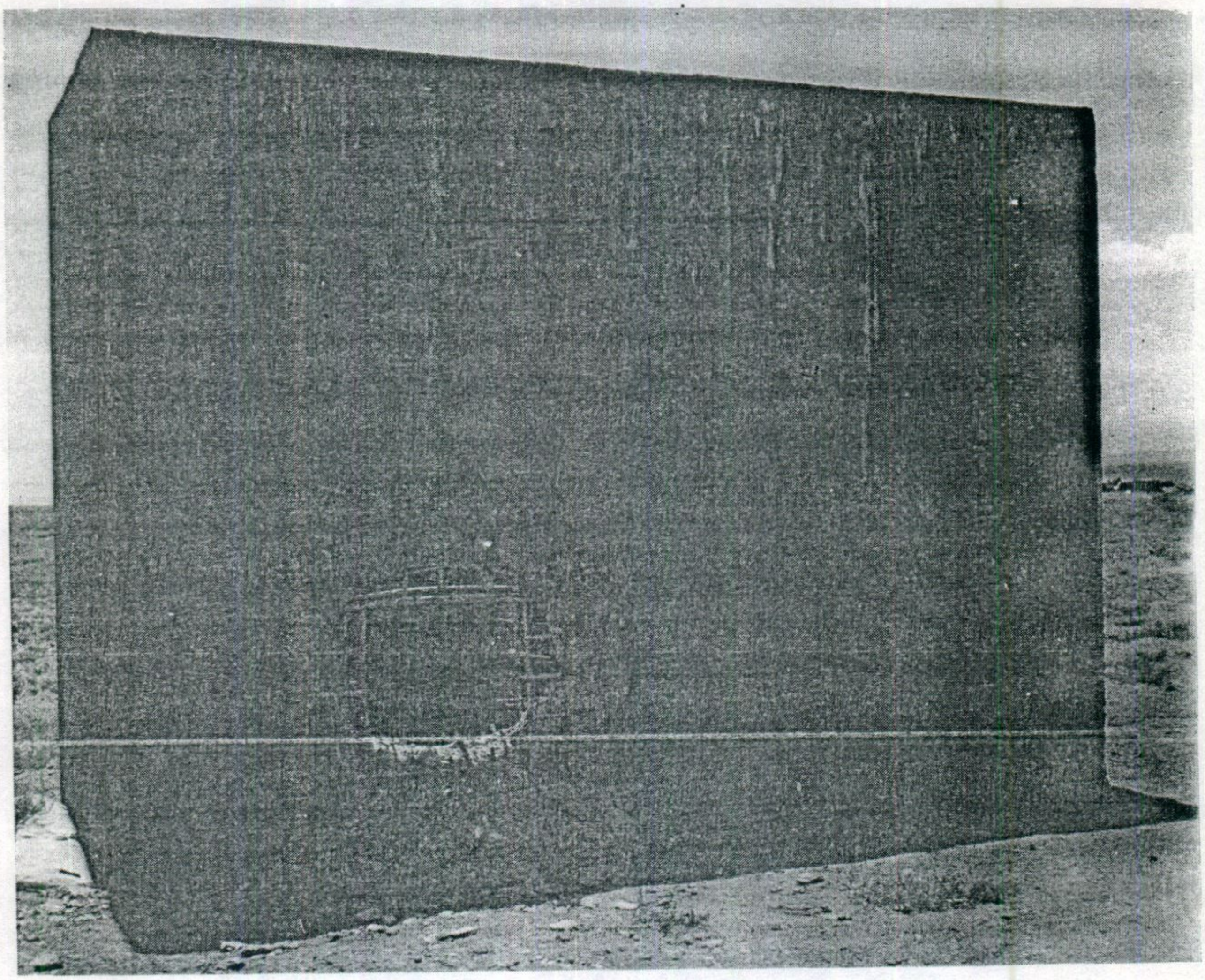


Figure 4-6. Eighteen-Inch-Thick Reinforced Concrete Wall Penetration

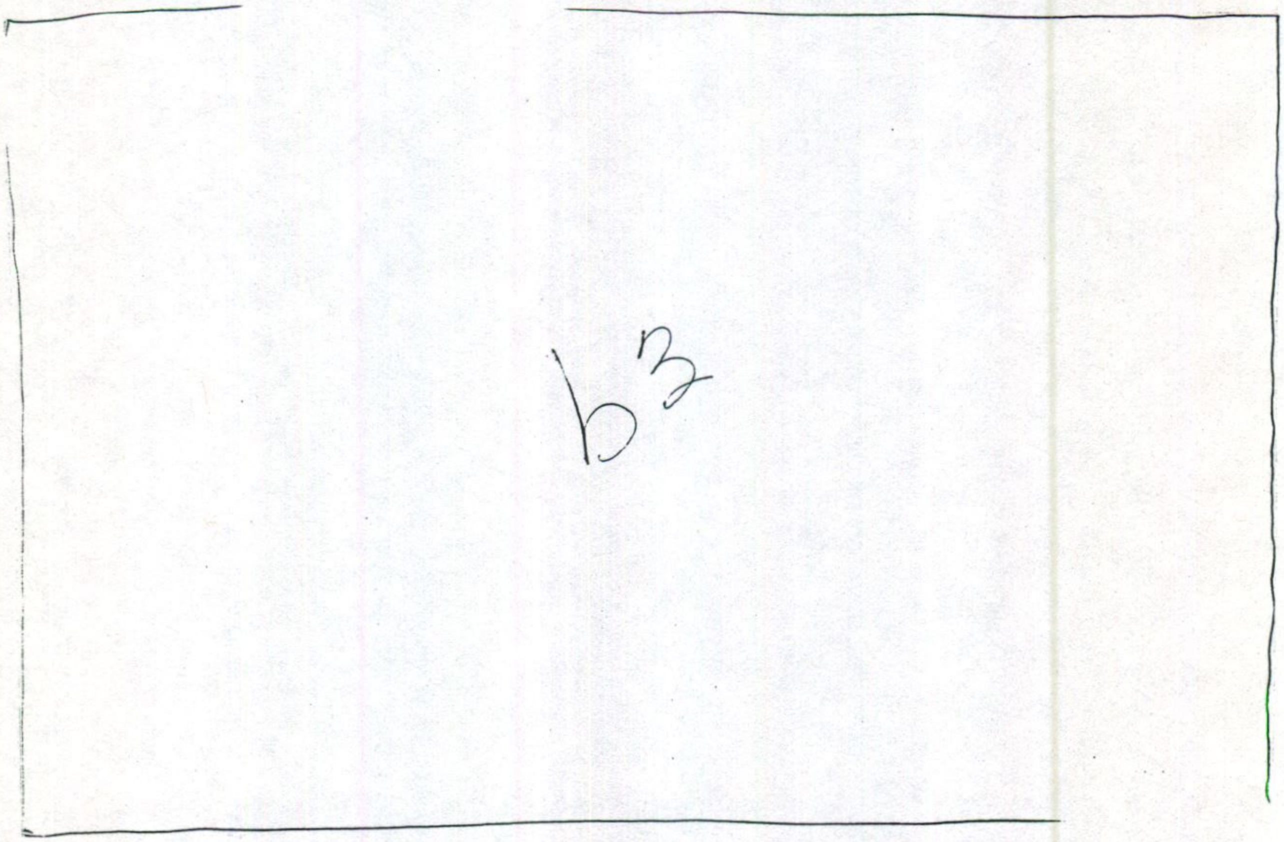
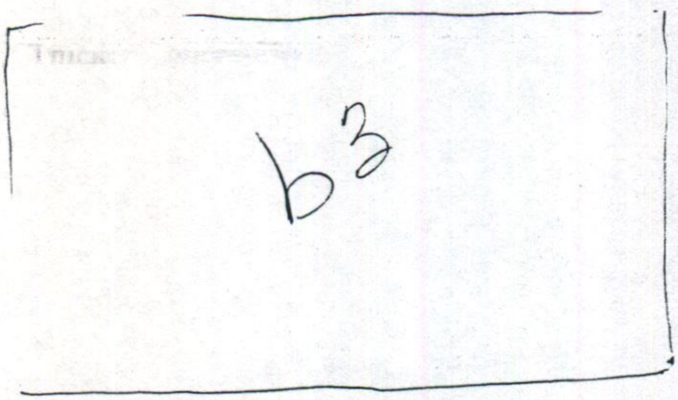
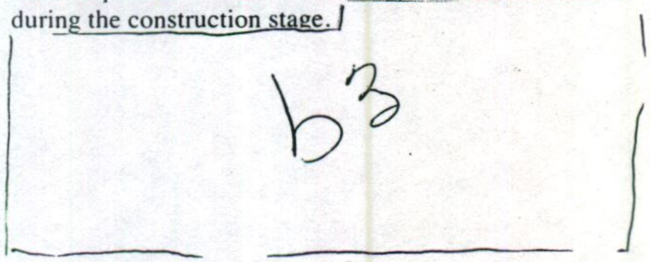


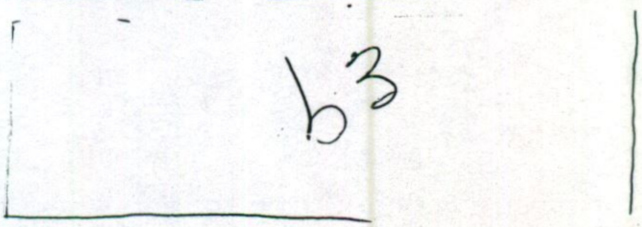
Figure 4-7. Penetration of 18-Inch-Thick Concrete Walls



Twenty-Four-, Thirty-Six-, and Forty-Eight-Inch-Thick Concrete Walls

Heavily reinforced concrete walls, 18, 24, 36, and 48 inches thick, have been tested with various explosives configurations. Figure 4-8 shows these walls, as well as three expanded metal-concrete walls (discussed later), during the construction stage.





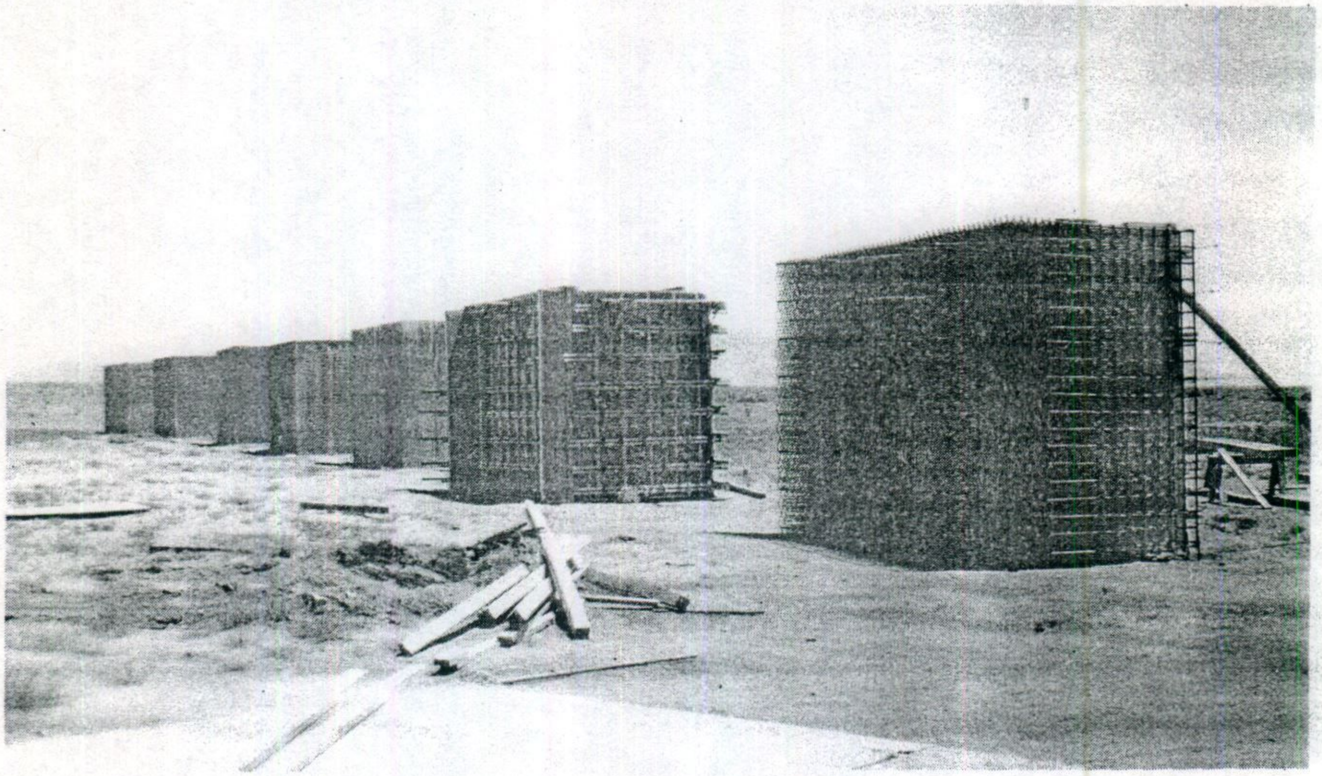


Figure 4-8. Thick Reinforced Concrete and Expanded Metal-Concrete Walls during Construction

Figure 4-9. Penetration of 24-Inch-Thick Concrete Walls

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Figure 4-10. Penetration of 36-Inch-Thick Concrete Walls

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Figure 4-11. Penetration of 48-Inch-Thick Walls

Figure 4-12. Approximate Amount of Explosive To Produce Crawl-Through Hole in Concrete Walls

Conclusions

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ADVANCED CONCEPTS FOR REINFORCED CONCRETE WALLS

In the design of new buildings to house nuclear materials or sensitive items, the incorporation of new configurations of concrete walls and concrete mixtures should be an important consideration. It is less expensive and more effective to use concrete walls of advanced design during initial construction than to attempt to upgrade standard walls at a later date. Experience gained in the evaluation of existing concrete wall penetration resistance has led to research in the area of advanced barrier concepts. Some possible improvements to concrete wall design are presented in the following subsections.

Steel-Concrete Sandwich Walls

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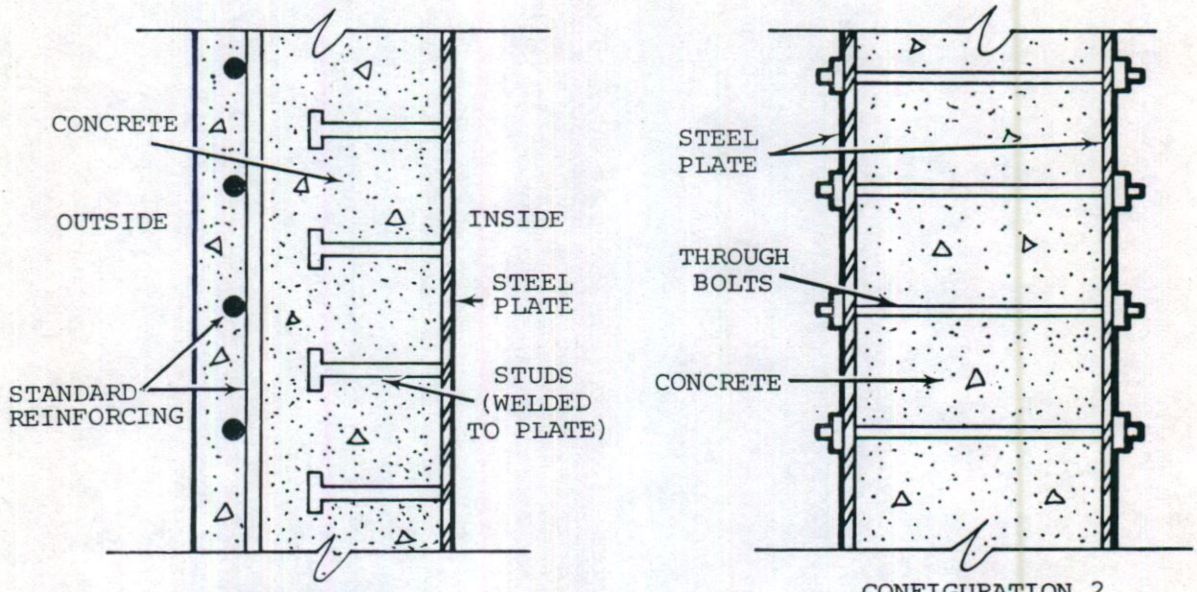

Figure 4-13. Sandwich Wall (Section)

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The cost of a sandwich wall would be approximately two to three times that of a standard reinforced concrete wall, but the steel plates could replace part or all of a separately constructed pouring form. If securely attached to the concrete, the plates might also function as reinforcement against structural tensile loads, thus decreasing the requirement for specialized reinforcing material. These two substitute functions, performed by the plates, serve to reduce the cost and may provide the means for a cost-effective barrier.

EXPANDED METAL-CONCRETE WALLS

Expanded metal-concrete walls are normally used in the construction of bank vaults. A typical wall section under construction is shown in Figures 4-8 and 4-16.

Expanded metal-concrete construction is dissimilar to standard reinforced concrete. In the version shown, vertical layers of 5/16-inch-thick, 3.64 lb/ft^2 expanded metal reinforcement panels are placed perpendicular to the wall face at 2½- to 3-inch centers. No. 6 rebars are strung

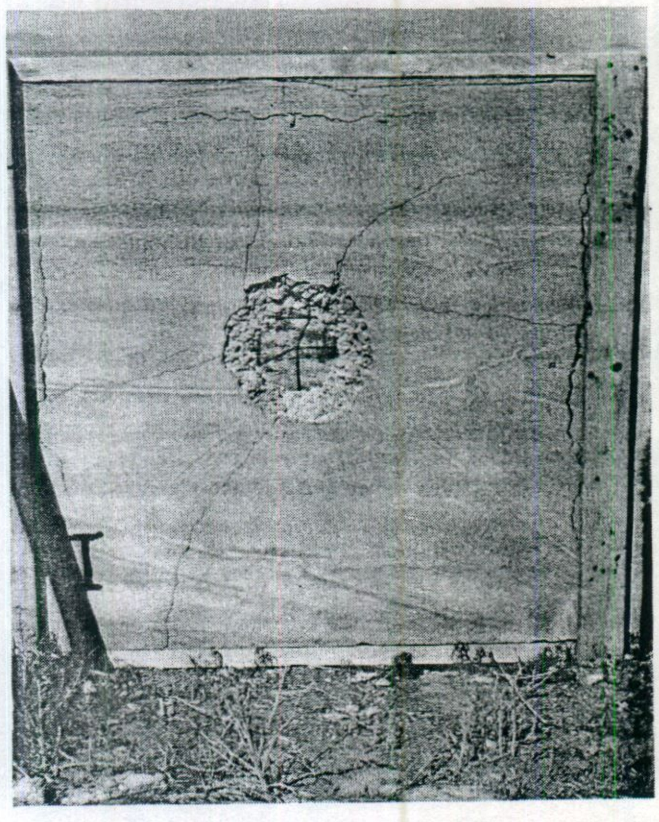

Figure 4-14. Penetration of 4-Inch-Thick Concrete Slab without Plates

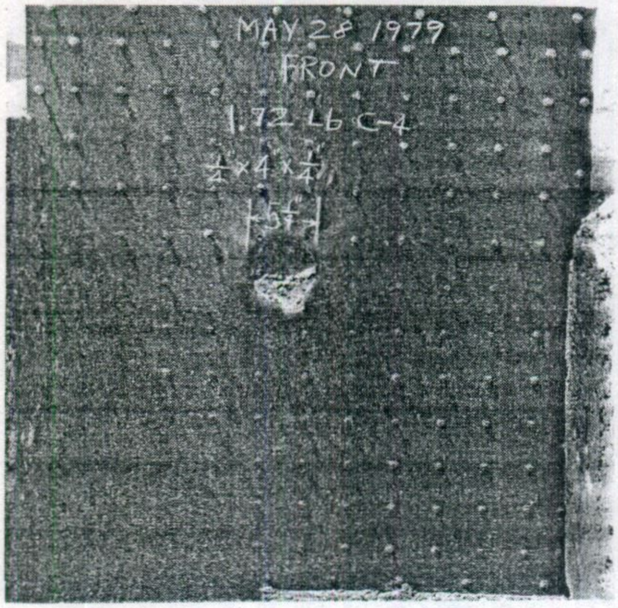

Figure 4-15. Penetration of 4-Inch-Thick Concrete Sandwich Wall with Plates Front and Back

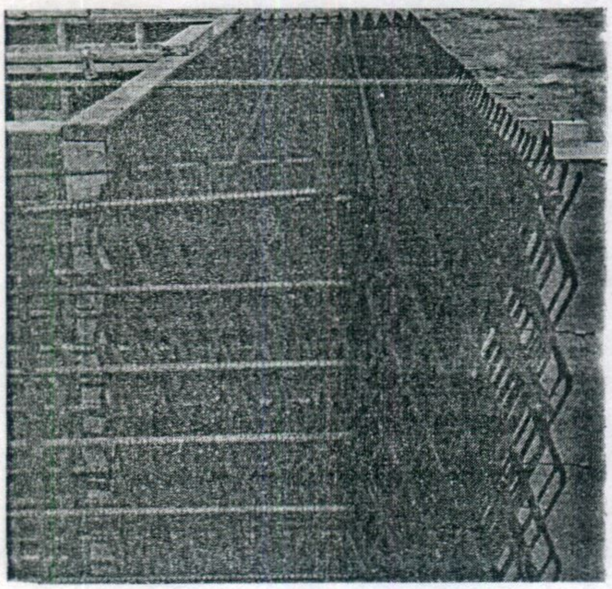

Figure 4-16. Expanded Metal-Concrete Wall Construction

through the expanded metal openings at 16-inch centers vertically and 6-inch centers horizontally. They are welded to the expanded metal to form a rigid structure. Then the concrete is poured around the reinforcement. In some walls, the sheets of expanded metal are placed in vertical layers parallel to the wall face. In another method, expanded metal sheets are stacked horizontally to form a concrete wall which contains approximately 50 pounds of steel per cubic foot. Expanded metal reinforcement weighing 6 lb/ft² is also available. Only the 3.64 lb/ft² configuration, described above and shown in Figures 4-8 and 4-16, has been tested by Sandia. Normally, 5000-psi concrete with an aggregate diameter of ½ inch or less (necessary because of the small spaces with in and between the expanded metal layers) is used in construction.

The cost of a 12-inch-thick expanded metal-concrete wall completely installed is approximately $35 per square foot (Albuquerque, New Mexico, FY79) compared to $25 for a 12-inch-thick standard 5000-psi concrete wall reinforced with two layers of No. 6 rebar on 6-inch centers.

Twelve-Inch-Thick Expanded Metal-Concrete Walls

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Eighteen-Inch-Thick Expanded Metal-Concrete Walls

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Figure 4-17. Penetration of Expanded Metal-Concrete Walls (12 Inches Thick)

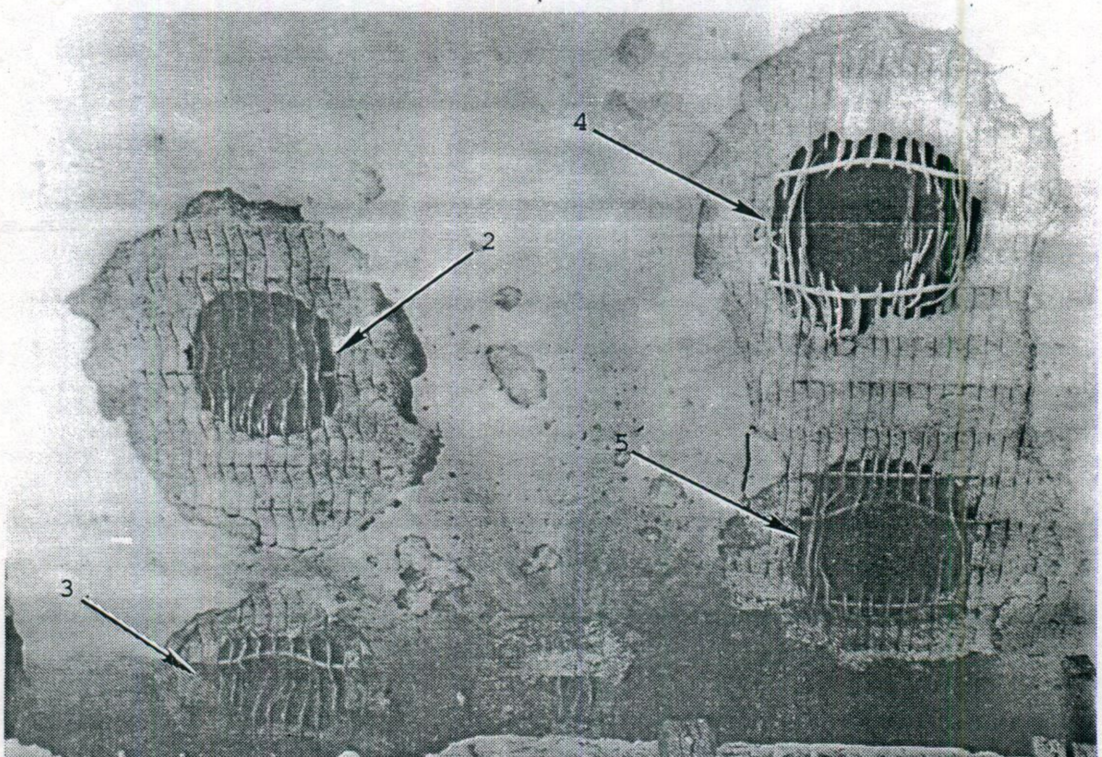

Figure 4-18. Penetration Tests of 12-Inch-Thick Expanded Metal-Concrete Wall (See Figure 4-17 for Test Data)

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Thicker Expanded Metal-Concrete Walls

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Figure 4-19. Penetration of Expanded Metal-Concrete Wall vs. Reinforced Concrete Wall (18 Inches Thick)

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Figure 4-20. Penetration of Expanded Metal-Concrete Wall (24 Inches Thick)

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Figure 4-21. Penetration of Expanded Metal-Concrete Wall (36 Inches Thick)

Conclusions

Conclusions to be drawn from tests and evaluations of expanded metal-concrete walls are that

[redacted]

4. The cost of expanded metal-concrete walls is approximately 40 percent higher than comparably reinforced standard concrete walls.

CONCRETE BLOCK WALLS

[redacted]

[redacted]

Figure 4-22. Penetration of 4-Inch-Thick Concrete Block Walls

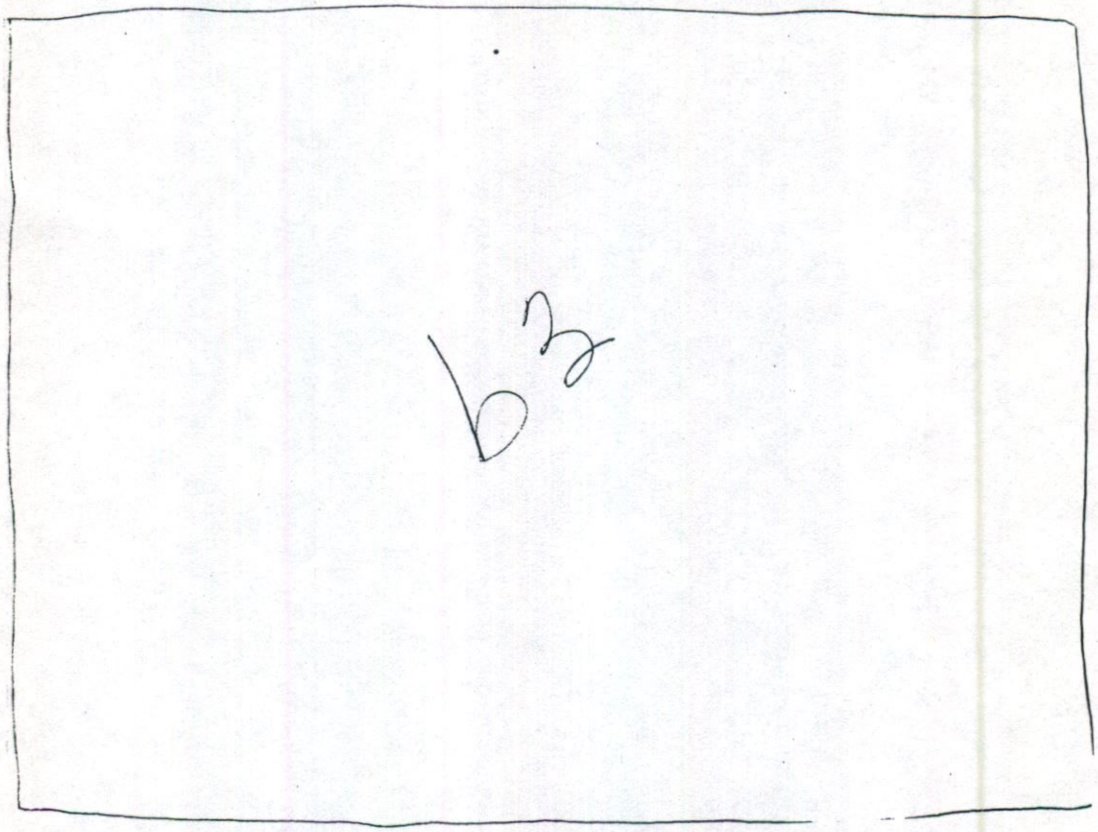

Figure 4-23. Penetration of 8-Inch-Thick Concrete Block Walls

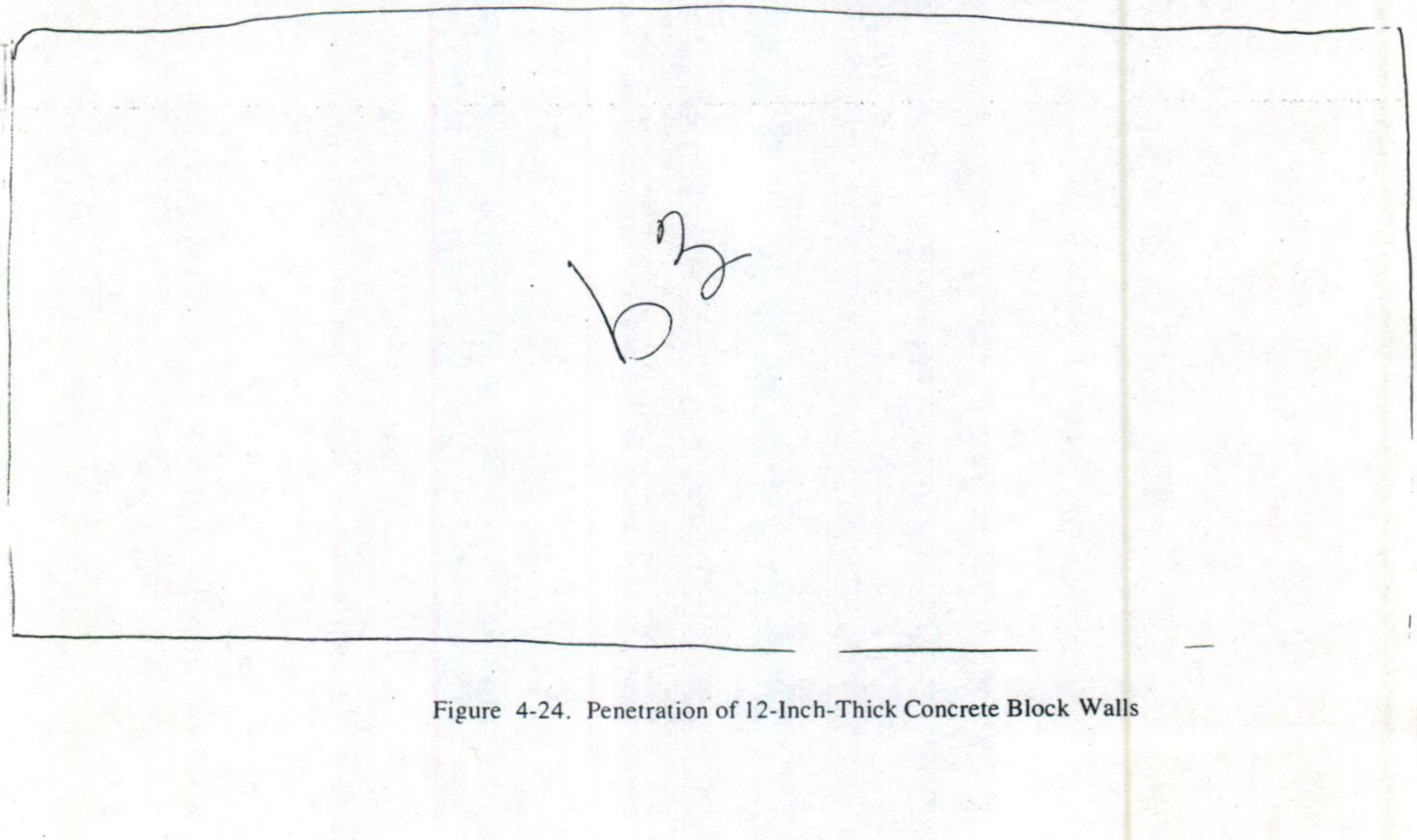

Figure 4-24. Penetration of 12-Inch-Thick Concrete Block Walls

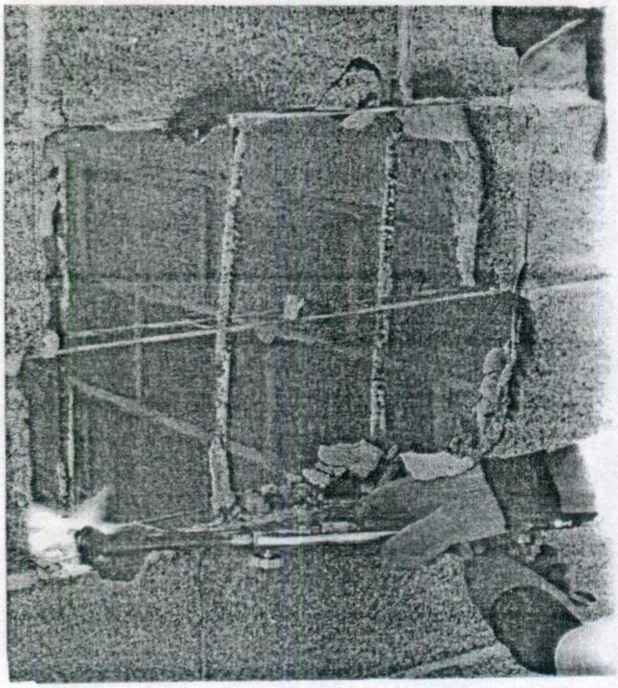

Figure 4-25. Penetration of a 4-Inch-Thick Filled and Reinforced Concrete Block Wall

Figure 4-26. Penetration of 12-Inch-Thick Filled and Reinforced Concrete Block Wall

Conclusions

Conclusions on the penetration resistance of concrete block walls are that

CLAY TILE WALLS

Clay tile walls have been used in some older buildings.

Figure 4-27. Penetration of Clay Tile Walls

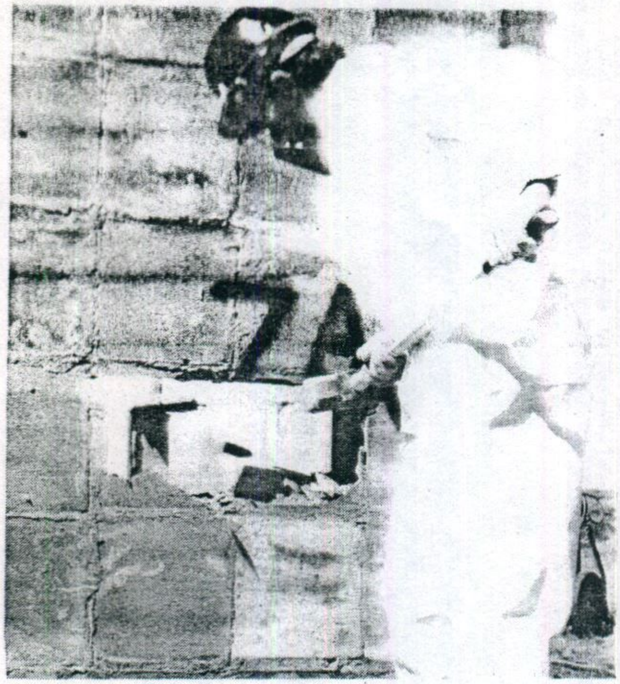

Figure 4-28. Penetration of an 8-Inch-Thick Clay Tile Wall

Conclusions

Conclusions on the penetration resistance of clay tile walls are that

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PRECAST CONCRETE TEE SECTIONS

Precast concrete tee sections are commonly used in building construction for walls, roofs, and floors. Figure 4-29 shows a typical cross section of a tee section. The outer edge of the flange where the tees join is 2 inches thick. The stem of the tee is reinforced with No. 3 rebar and pretensioning steel, but the flange is reinforced only with 12-gauge woven-wire fabric. No. 4 rebars, which are used to join sections, are cast into the flanges at an angle and are widely spaced.

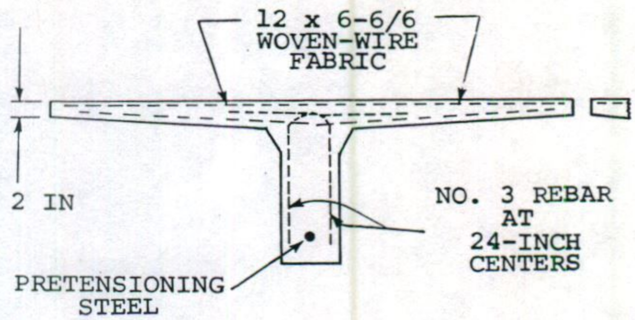

Figure 4-29. Cross Section of a Typical Tee Section

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Figure 4-30. Penetration of Precast Concrete Tee Section

CORRUGATED ASBESTOS WALLS

Asbestos wall material is compounded of asbestos fiber and Portland cement. Corrugated asbestos is available in thicknesses ranging from ⅛ inch to ⅜ inch. Exterior curtain walls of ⅜-inch-thick corrugated asbestos can be found in existing buildings. Figure 4-31 shows a typical cross section of corrugated asbestos.

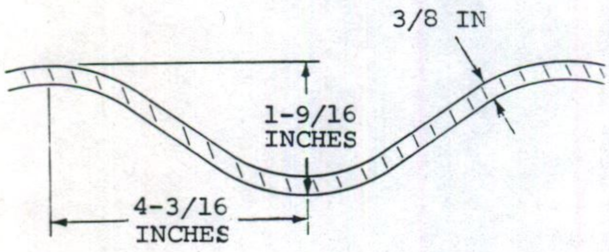

Figure 4-31. Corrugated Asbestos—Typical Cross Section

WOOD FRAME WALLS

Numerous tests of wood frame walls and these walls used in combination with other materials for greater strength and extended delay have been conducted by the National Bureau of Standards.[4,5] Detailed penetration test data on specific wood frame walls are included in Chapter 15. A summary of test results is presented in Figure 4-32.

Figure 4-32. Penetration of Wood Frame Walls

ADVANCED WALL DESIGN CONCEPTS

Walls can be designed to provide prolonged penetration delay against hand or power tools. If an explosive is used as the attack tool, advanced wall designs which will appreciably extend the penetration delay are more complex and more expensive to construct. However, increasing the barrier potential of wall designs through advanced techniques will also force the attacker to use more sophisticated tools and methods.

Fibrous Concrete

Fibrous concrete is not a new material but has seen accelerated use in the last decade. It is used mainly for airport runways and roads where impact loads and surface wear are experienced. Its cost is approximately twice that of standard reinforced concrete.

The composition of fibrous concrete can vary, but it essentially consists of a concrete matrix containing a random dispersion of small steel fibers ranging from 0.006 to 0.030 inch in diameter and 0.25 to 3 inches long.[6] The steel fibers toughen the concrete, increase its resistance to impact and shock loads, and increase the flexural strength to 40 to 60 percent of the compressive strength (standard concrete flexural strength is 20 percent of the compressive strength).

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Stand-Off Walls

An obvious method for protecting concrete walls from rapid penetration by explosives or for complicating the penetration is to attenuate the explosive energy reaching the wall. A concept for preventing the attachment of explosives directly to the surface of a wall has been investigated.

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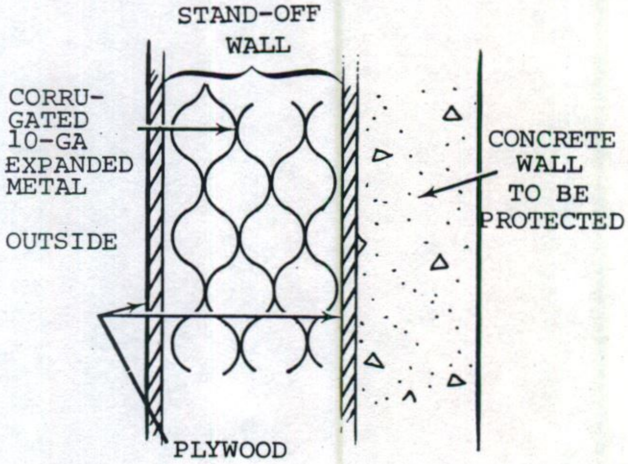

Figure 4-33. Cross Section of Stand-Off Wall

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Lattice Walls

In order to overcome the vulnerability factors of bulk concrete walls, such as brittleness, susceptibility to fracture, and spalling, an experimental wall panel constructed of numerous connected individual metal channels was fabricated and tested. Figure 4-37 shows a cross section of a lattice wall panel.

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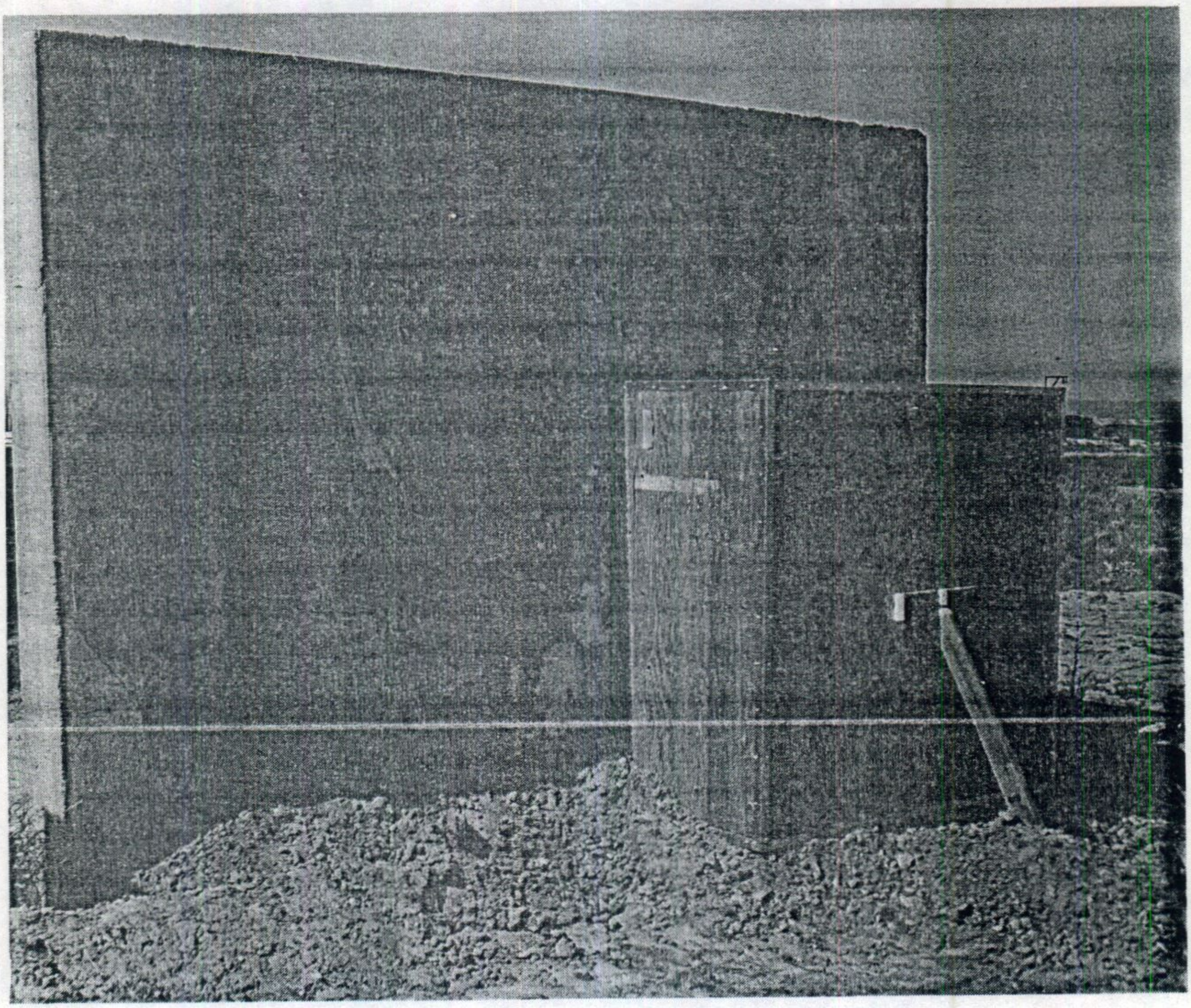

Figure 4-34. Stand-Off Wall with Explosive Charge in Place

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Figure 4-37. Penetration Resistant Panel

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CHAPTER 5

ROOFS AND FLOORS

INTRODUCTION

This chapter presents some contemporary roof and floor construction techniques along with comparative penetration times. Roofs and floors function as climatic barriers, provide working surfaces, and to some degree function as protective barriers; however, their use as physical protection against penetration by determined adversaries is generally not considered. The penetration threats include hand, power, and thermal tools and explosives, used alone or in combination.

Construction methods and materials used for roofs and floors are similar. The basic materials may vary slightly in total thickness, type and quantity of steel reinforcement, and the concrete strength required to carry the loads (designed live and dead loads). In general, floors offer more resistance to penetration than roofs do because they are protected by the main structure and are designed to accommodate heavier loads than roofs are. A floor may be considered as a roof with the membrane and insulation removed.

Contemporary roof types used on many structures include

Type 1: Prestressed concrete tee beams with lightweight concrete, insulation, and a roofing membrane.

Type 2: Metal subdeck with reinforced concrete, insulation, and a roofing membrane,

Type 3: Metal roof deck with lightweight concrete, insulation, and a roofing membrane,

Type 4: Metal roof deck with insulation and a roofing membrane,

Type 5: Metal roof with insulation below,

Type 6: Reinforced concrete beams and slab with insulation and a roofing membrane, and

Type 7: Wood sheathing with a roofing membrane.

The designation of Types 1 through 7 has been adopted solely to facilitate discussion in this handbook. The definitions of these types are not intended to provide a complete description of the different roof types. The rest of this chapter discusses each of these roof types in detail and breaks them down into the elements of membrane, insulation, main deck, and subdeck. Several modifications and enhancements for the various roof types are also presented.

63

ROOF PENETRATION

Type 1—Prestressed Concrete Tee Beam

A Type 1 roof is constructed with prefabricated, prestressed concrete tee beams, lightweight concrete, rigid insulation, and a three-ply, coal tar pitch, built-up roofing membrane with gravel. The Type 1 roof gives the appearance of a structure which should provide good penetration resistance (Figure 5-1). The tee beams are fabricated in different lengths and depths, as required by the load capacity; the web is reinforced with stressed reinforcing cables. The flange is usually constructed with 10-gauge, 6- by 6-inch welded wire fabric (WWF). The normal method of attachment consists of welding the bearing surfaces at the base of the web to the structural framing. The flange joints are secured to each other at the shear ties, which are cast into the beams during fabrication (Figure 5-2). The number of shear ties, usually a minimum of four, is determined by the length of the beam. The lightweight concrete is emplaced with no reinforcement (as is the usual construction practice) and with the insulation and roofing membrane installed.

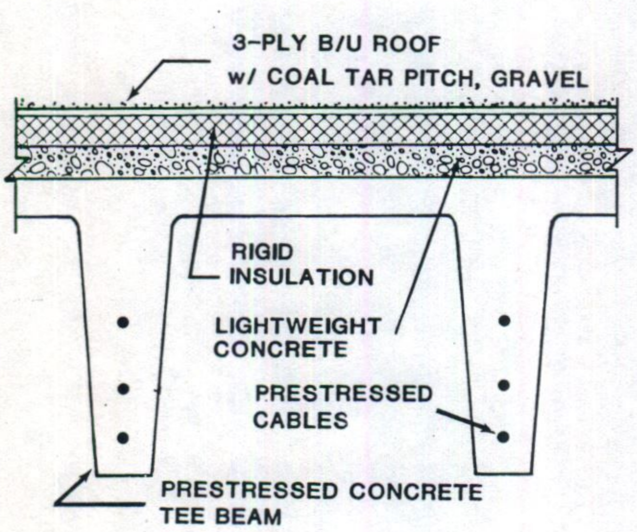

Figure 5-1. Type 1—Prestressed Concrete Tee-Beam Construction

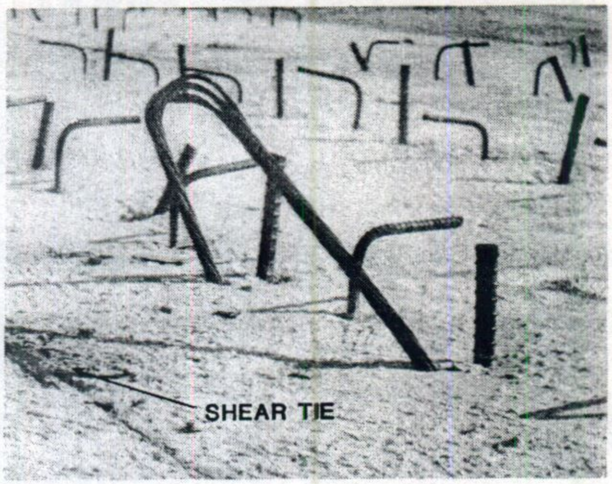

Figure 5-2. Example of Shear Tie and Flange Joints

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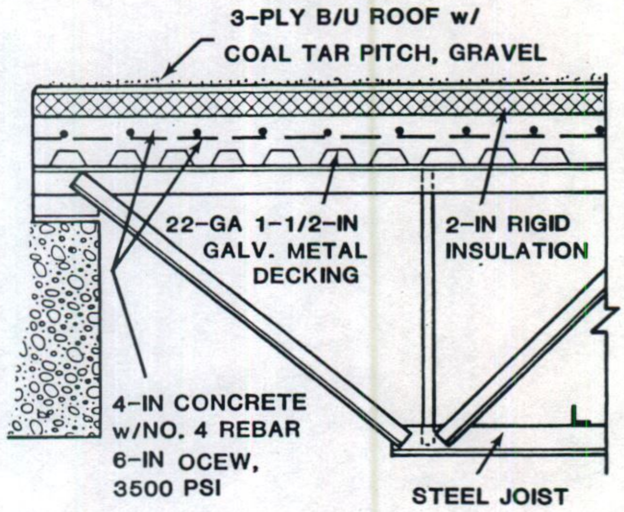

Figure 5-5. Type 2—Metal Subdeck and Reinforced Concrete

b3

Type 2—Metal Subdeck and Reinforced Concrete

A Type 2 roof is constructed with a ribbed metal subdeck, standard reinforced concrete, rigid insulation, and a three-ply, coal tar pitch, built-up roofing membrane with gravel. The Type 2 roof is considered a substantial roof (Figure 5-5). The metal subdeck is installed on the metal joists and welded together with the ends overlapped approximately one rib section. Standard 3500-psi reinforced concrete is used. The concrete is 4 inches thick and contains No. 4 steel rebar spaced 6 inches on center each way. The rigid insulation and roofing membrane which are applied to the Type 2 roof slab are the same as those used in the Type 1 roof.

b3

b3

Type 3—Metal Roof Deck with Lightweight Concrete

A Type 3 roof is constructed with a metal roof deck, reinforced lightweight concrete, rigid insulation, and a three-ply, coal tar pitch, built-up roofing membrane with gravel (Figure 5-8). The Type 3 roof is used on structures with a moderate roof load. This roof is similar to Type 2 in construction except that the reinforced concrete is replaced by reinforced lightweight concrete which contains an aggregate of Zonolite, pumice, or similar materials having a loose weight of 70 lb/ft^3 or less.[1] Concrete reinforcement consists of 10-gauge, 6- by 6-inch WWF (Figure 5-9).

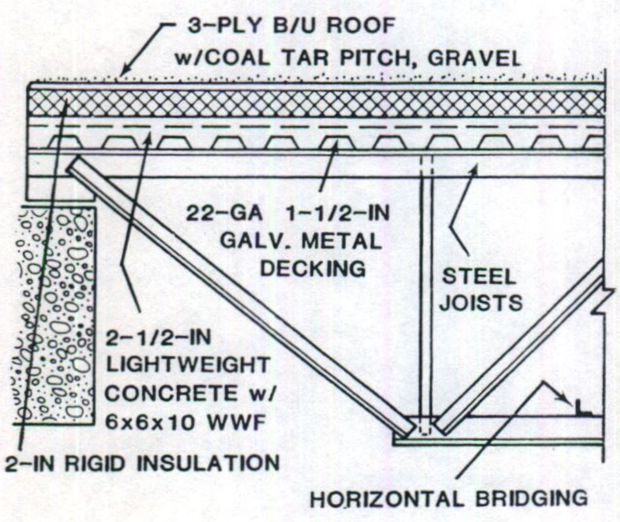

Figure 5-8. Type 3—Metal Roof Deck with Lightweight Concrete

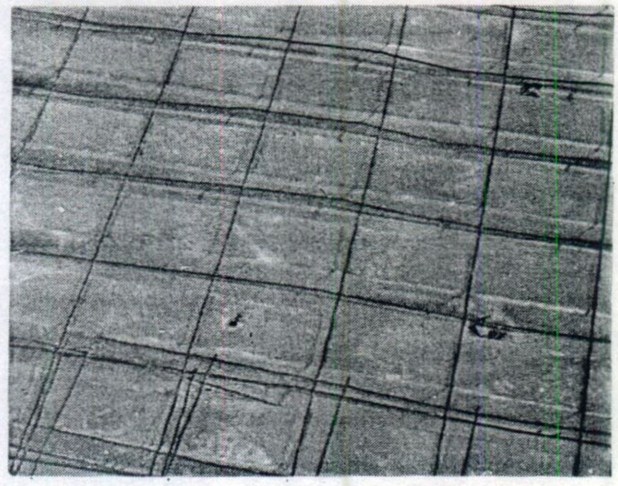

Figure 5-9. Reinforcing for Lightweight Concrete (6x6x 10 WWF)

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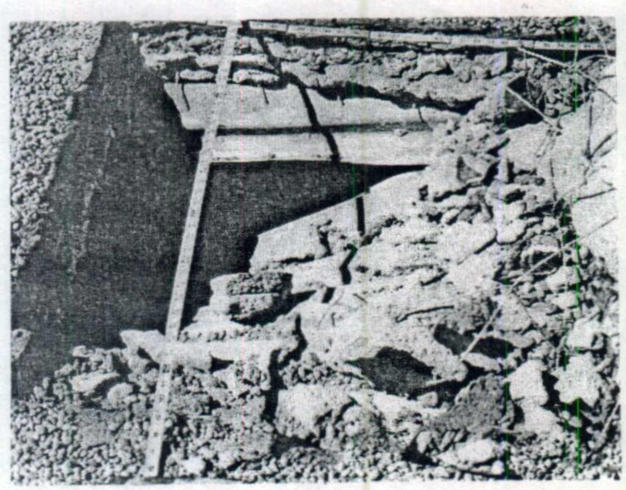

Figure 5-10. Penetration of Type 3 Roof Using Hand Tools

Type 4—Metal Roof Deck With Insulation

The Type 4 roof is constructed with a metal roof deck, rigid insulation, and a three-ply, coal tar pitch, built-up roofing membrane with gravel (Figure 5-11). The Type 4 roof is used on light structures. Since each of the three roof elements (membrane, insulation, and main deck) have been previously discussed under other roof types, they will not be discussed further.

b3

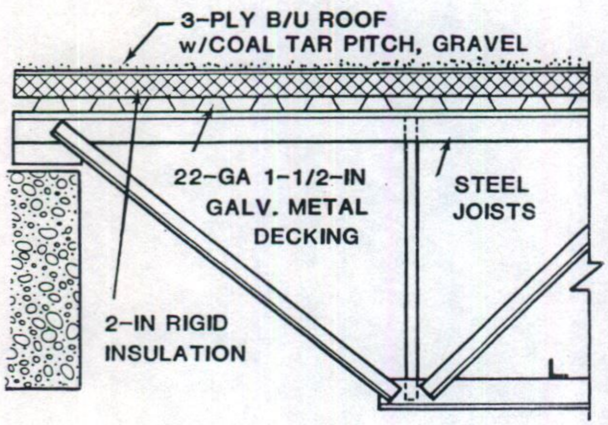

Figure 5-11. Type 4—Metal Deck with Insulation

Type 5—Metal Roof (Insulation Below)

The Type 5 roof is constructed of 24-gauge corrugated metal with 1½ inches of fiberglass insulation and a wire fabric (Figure 5-12).

b3

Type 6—Reinforced Concrete Beam and Slab

The Type 6 roof is constructed with heavily reinforced concrete beams, a concrete slab for the main roof deck, rigid insulation, and a built-up roofing membrane (Figure 5-13). The Type 6 roof is used on some multistoried facilities and offers better resistance to penetration than most other roofs. The main deck may be 6 inches or

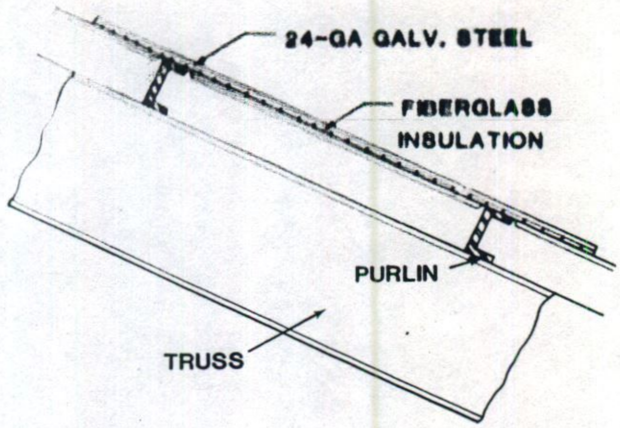

Figure 5-12. Type 5—Sheet Metal Construction

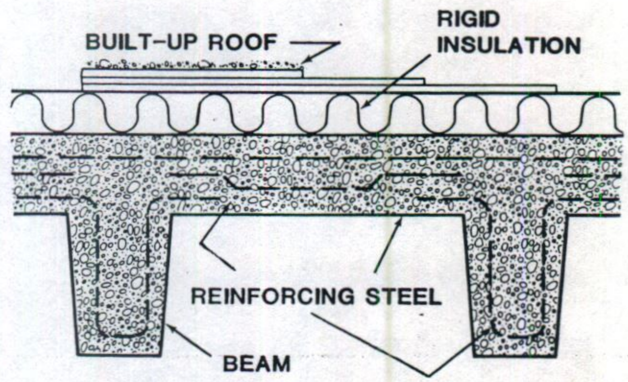

Figure 5-13. Type 6—Beam and Slab Construction

more in depth with multiple layers of reinforcing steel, making it similar in construction to a wall.

b3

Type 7—Wood Sheathing with Membrane

The Type 7 roof construction consists primarily of wood materials and contains a wood sheathing, rigid insulation, and a built-up roofing membrane (Figure 5-14). It is inexpensive and hence is commonly used in many small structures although its use is discouraged by most

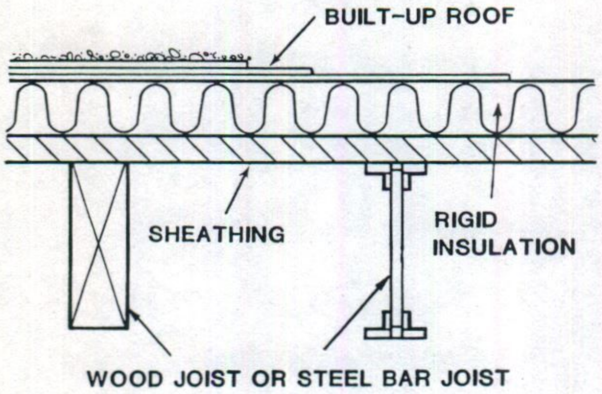

Figure 5-14. Type 7—Wood Construction

fire codes.

b3

ROOF UPGRADES—VULNERABILITY AND ENHANCEMENTS

There are many potential enhancements which can be made to the seven types of roofs and their elements. Enhancements suggested in this handbook do not apply directly to any one roof type but rather to the roof elements. Below-the-roof-line enhancements are also discussed.

b3

Membranes

Vulnerability — The membrane consists of a three-ply roofing felt with either coal tar pitch or roofing asphalts and gravel or slag embedded in the flood coat. It is vulnerable to hand and power tools and can be peeled away in large sections to expose the next roof element.

Enhancements — The membrane has inherent penetration deterrents such as the capability of fouling some cutting tools. Because of its self-healing nature, coal tar pitch may be more suitable for this function than roofing asphalts on some roofs.

b3

Insulation

Vulnerability — Rigid insulation board can be penetrated with many types of hand and power tools and removed in large pieces if it is not secured to the main or subroof deck. When the insulation is 2 inches or less in thickness, it is usually a frangible material.

b3

Rigid insulation can be lifted by winds blowing over a roof and, therefore, in order to meet building codes the insulation must be adequately secured. In effect, this added securement is an enhancement. The insulation is secured by installing fasteners through the insulation and attaching these fasteners to the main deck. There should be one fastener for every 2 square feet of insulation. For added enhancement, the amount of free (unsecured) area of insulation can be further reduced by increasing the number of fasteners to one fastener for each square foot of insulation. To ensure adequate penetration delay, the method selected for retaining the insulation must be secured to the main roof deck. The previously suggested screen or mesh for the membrane may also function as an enhancement to insulation.

When an additional thickness of insulation is employed, it can be sandwiched and used to conceal other deterrents, even some form of dispensable deterrent.

Main Decks

Lightweight Concrete

Vulnerabilities —

b3

Enhancements —

b3

Standard Reinforced Concrete

Vulnerabilities —

b3

Enhancements —

b3

Corrugated Roof

b3

Subdeck System

Metal Systems

b3

Precast Concrete Tee Beams

b3

b3

Below-the-Roof-Line Enhancements

Penetration tests have indicated that barriers placed below the roof are sometimes more effective against penetration than those in the roof itself. Such barriers may be used in some existing structures without major modification. Placing these enhancements below the roof line provides them with some protection against direct attack and could make a second penetration necessary. This second penetration could be constrained to take place in a confined area and could force the use of tools from other tool classes in order to complete penetration.

b3

b3

FLOOR CONSTRUCTION

The similarity in design and construction of roofs and floors, together with the preceding discussion of roof construction concepts, obviates the need to present detailed information on floor construction. Fabrication includes an increase in size and strength of structural members to carry the increased live and dead loads, which are sometimes in excess of 500 lb/ft^2. This additional strength provides floors with greater penetration resistance than most roofs have. Some finishing materials which are used to cover floors, e.g., asphalt floor covering, etc., contribute little to penetration resistance. Floors constructed below ground or on grade would require tunneling or the removal of a considerable excavation to achieve penetration.

Penetration modes similar to those used against roofs can generally be employed against floors; however, when a larger amount of explosives is required for penetration, there is the possibility that the overpressure from the detonation may cause structural failure to other elements. The amount of internal pressure that a facility can withstand without a structural failure will have to be determined for the individual facility.

There are existing enhancements built into some floors, such as under-the-floor ducts (e.g., power, communication, etc.), that may increase resistance and reduce the clearance needed for a penetration. The installation of utility, plumbing, and heating and air-conditioning systems below the floors may also hinder penetration. Enhancements may also be added below the floors. Comparative floor penetrations are summarized in Figure 5-16.

Figure 5-15. Comparative Roof Penetration Times

Figure 5-15. Comparative Roof Penetration Times (continued)

Figure 5-15. Comparative Roof Penetration Times (continued)

b3

Figure 5-16. Comparative Floor Penetration Times

REFERENCES

1. *Building Code Requirements for Reinforced Concrete*. ACI Standard 318-71, ANSI A 89.1, 1977.

2. Dan A. Watson, AIA, FCSI, *Construction Materials and Processes* (New York: McGraw-Hill, Inc., 1972).

3. Richard M. Simmons, *Barrier Technology Roof Penetration Tests(U)*. SAND79-1987 (Albuquerque: Sandia National Laboratories, July 1980). (CNSI).

Chapter 6

CHAPTER 6

DOORS

INTRODUCTION

In all structures, the value of a barrier is ultimately determined by its weakest portion. This chapter presents evaluations of the various doors used in typical industrial facilities and applies the criterion of balanced design, which is necessary to the effectiveness of a barrier array. Doors are classified as

- Standard industrial doors
  - Personnel
  - Vehicle
- Igloo doors
- Vault doors

Penetration delay time through static structures can be increased through the use of thicker and/or composite materials. Doors, however, due to their functional requirements and associated hardware impose design restrictions and are, in many cases, one of the weakest links in a structure. For example, many buildings with heavy concrete walls provide pedestrian access through commercial hollow, steel doors. The barrier value of the basic structure is relatively high, but it is weakened by the use of ordinary doors, frames, and hinges which can be quickly penetrated.

Consequently, for barrier purposes, the principle of balanced design requires that doors with associated frames, hinges, bolts, and locking mechanisms be strengthened to afford the same penetration delay as is provided by the floors, walls, and ceilings of the parent structure. Conversely, if the door assembly cannot be enhanced, it may not be cost-effective to upgrade the building structure.

Unfortunately, with the exception of vault or blast doors, no currently available standard pedestrian doors and associated hardware provide significant penetration resistance against determined adversaries. New designs are needed to provide doors which will match the penetration resistance of the more rugged structures.

PERSONNEL DOORS

Personnel doors vary in type, style, and class, but most common exterior doors are 1-¾ inches thick with 16- or 18-gauge (0.060- or 0.048-inch) steel surface sheets. Construction is usually hollow-core or composite with or without glass or louvers. A composite door core consists of a noncombustible, sound-deadening material, usually polyurethane foam or slab. Light-gauge vertical reinforcement channels are sometimes used inside hollow core doors to add strength and rigidity to the door assembly.

Steel pedestrian doors are found throughout government and private industry in single or double configurations and use a wide variety of locking devices.

Exterior doors usually swing outward, regardless of their functional design, and have their closing devices attached internally. Hinges are mortised with either removable or nonremovable pins. Additional doors are provided for emergency exits, as required by fire and safety codes.

The requirements for panic-bar devices on all emergency exits make any door only a one-way barrier. This design requirement provides a variety of exit modes to outside attackers after a building has been breached.

Penetration times for lightweight sheet steel doors vary depending on the attack tools used. Penetration time through either standard hollow-core or composite doors is essentially the same.

Figure 6-1 presents penetration times for standard industrial pedestrian doors.

Attack Modes

Door Faces

b3

Panic Bars

b3

Locks

b3

b3

Many doors need no entrance modes at all (only exit modes) and therefore can be fully flush-mounted with no external hardware. If keyways are required, there are several "high-security" locks on the market that require quite long pick times. For additional lock information, see Chapter 14: "Locks."

Hinge Pins

b3

Louvers, Windows, Mesh

b3

Conclusions

Standard industrial doors are vulnerable to a number of attack modes. Improved designs are necessary to upgrade the penetration resistance of industrial doors to match the delay provided by the remaining structure.

b3

Upgrades and Improved Design Concepts

Steel pedestrian doors mounted in stamped steel frames are frequently found in existing facility structures. These doors offer little resistance to forcible attack; however, they can be upgraded in various ways to increase their penetration delay time. The upgrades and design concepts described in the following subsections are intended to balance the overall door structure, i.e., face, frame, hinges, exit devices, louvers, glazing, and locks, and protect it against forcible penetration attempts which employ hand, power, or thermal tools. b3

Figure 6-1. Penetration Times for Standard Industrial Pedestrian Door

b3

Eliminating all unnecessary doors is the first step in upgrading existing facilities. Eliminating all windows, louvers, and external knobs and keyways is another order of upgrade.

Steel Plates

One structural enhancement is the addition of steel plates to door surfaces; this increases the penetration resistance of a door to hand and light power tools. Heavy-duty hinges should be used to support any added weight, and frames should be grouted to strengthen the supporting structure.

Redwood Cores

Redwood cores placed between door plates increase the delay times for thermal cutting tools by a factor of between 3.5 and 4 times that of an air void. The penetration resistance to explosives or tool attacks of a door upgraded with a redwood core has not been evaluated. Other types of wood might produce the same results as redwood does against thermal tools; however, no other types have been tested.

Locks and Frames

b3

A method has been devised to prevent easy access to the lock/frame area. A 10-gauge sheet steel strip can be either welded or bolted to the door (see Figure 6-2). This strip should be the same height as the door and at least 2 inches wide, with a 1-inch overlap onto the adjacent door frame. In addition, the frame should be grouted with concrete mix at least 18 inches above the frame strike location. Holes can be cut in the door frame to allow grouting of both sides of the frame. The holes could then be covered with a cover plate which is welded or screwed into place. A high-security lock could also be installed on exterior pedestrian doors since lock defeat is one of the quickest and quietest means of gaining entry to a protected area (see Chapter 14).

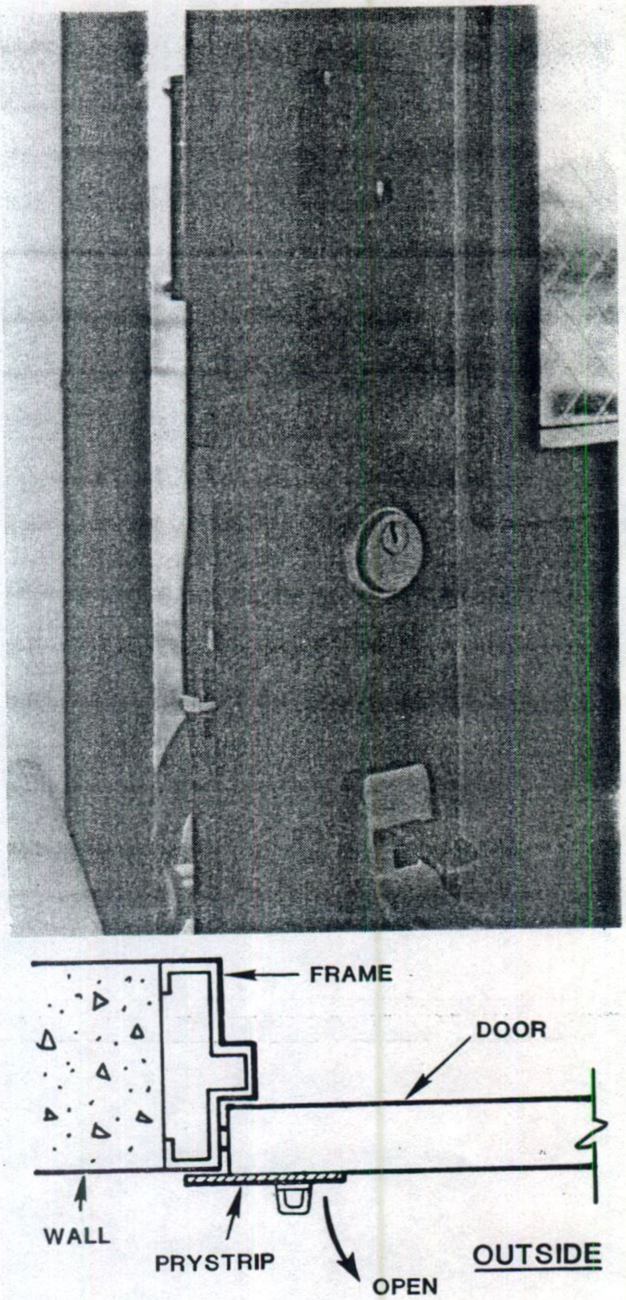

Figure 6-2. Pry Strip

Hinges

b3

b3 [redacted]. Upgraded hinges with a stud-in-hole feature (see Figure 6-3) are commercially available. This type of hinge extends penetration time. Another method devised to prevent hinge-side door removal employs a Z-strip made from 10-gauge steel, which is bolted or welded to the rear face of the door (see Figure 6-4). This strip is formed so that if the door hinges are removed and an attempt is made to pry the door from its frame, one leg of the Z-strip will come in contact with either the inner frame surface or the rear door stop surface (see Figure 6-4a).

b3 [redacted]

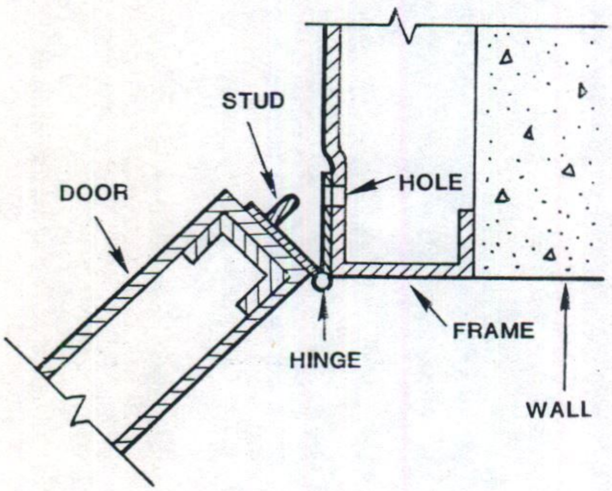

Figure 6-3. Hinge Upgrade

Panic Bars

Most exterior doors are equipped with "panic" hardware which allows rapid exit in case of emergency. However, this safety equipment also makes a door more vulnerable to defeat. Upgrades are needed which will lessen this vulnerability.

b3 [redacted] One possible method of upgrading a panic-bar-equipped door employs a bent metal plate with a drill-resistant steel section fastened to it (see Figure 6-4b). The plate prevents chiseling and wire hooking of the panic bar, while the drill-resistant section extends penetration time considerably if the area between the panic bar and the horizontal leg of the plate is attacked. If any other location on the door is selected for drilling, wire manipulation becomes considerably harder since the wire hook may hit the horizontal leg when pulled.

- Tests involving prying attacks on doors equipped with panic hardware indicate that mortise-type panic hardware resists penetration much longer than rim-type hardware. When a door is pryed, the rim-type panic bar attachment screws can either shear or pull out of the rear door face.

Louvers and Glazing

b3 [redacted]

Possible upgrades include the addition of a screen or a bar grid to the interior of the louver or glazing (see Figures 6-4c and 6-4d). For additional information on screens and bar grids, see Chapter 8: "Utility Ports." Glass or plastic glazing materials are discussed in Chapter 7: "Windows."

Multiple Dead Bolts

Replacement of a single conventional dead bolt with a high-security multiple dead-bolt system would virtually eliminate prying attacks.

Air Locks

Attacks on industrial doors using explosives present different design problems. For practical purposes, air locks or a series of doors for either pedestrians or vehicles can be used for upgrading existing facilities. In an area where a limited number of personnel might use an emergency exit, a one-way turnstile could be used inside of the exterior door to prevent rapid penetration by an adversary.

Exit Tunnels

The insider breakout threat through emergency exits or normal portals can be controlled by the use of hardened exit tunnels which lead to hardened and safe holding areas (see Figure 6-5).

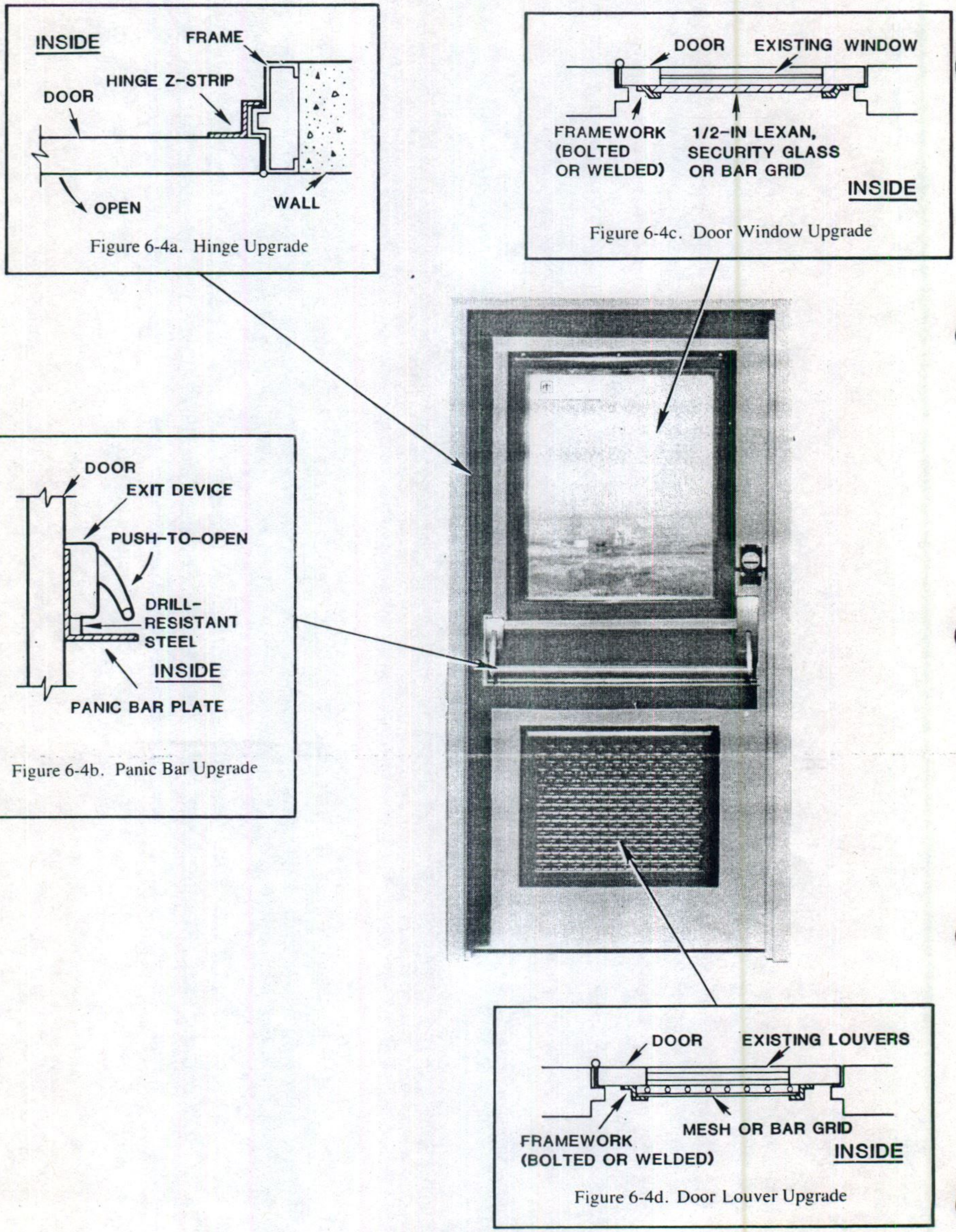

Figure 6-4a. Hinge Upgrade

Figure 6-4c. Door Window Upgrade

Figure 6-4b. Panic Bar Upgrade

Figure 6-4d. Door Louver Upgrade

Figure 6-4. Upgraded Door

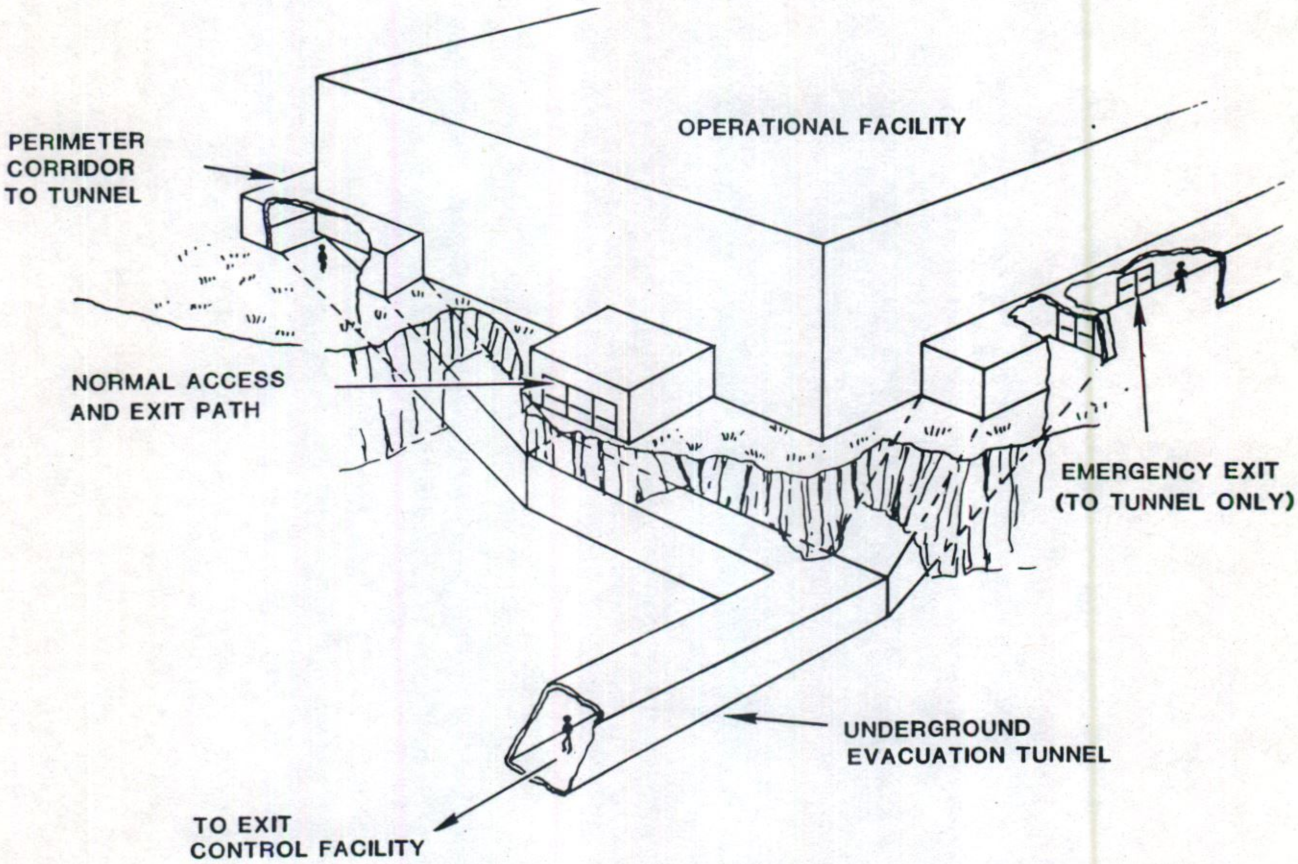

Figure 6-5. Emergency Exit Tunnels

VEHICLE ACCESS DOORS

Many of the foregoing considerations on vulnerability, attack modes, hardware, and upgrading of pedestrian doors also pertain to vehicle access doors. This is especially true where the construction of the doors is essentially identical and the main difference is size. A vehicle doorway is one of the largest structural openings which needs to be protected. Corrugated roll-up and hollow-steel panel doors are found throughout industrial and government buildings. Standard industrial doors are available in swinging, sliding, rolling, telescoping, bifolding, and biparting designs. They are used primarily to minimize the effects of weather, noise, and pollutants or to provide privacy. Many vehicle access doors seriously degrade the barrier value of a substantial structure because they have not been designed to resist forcible entry.

b3

b3

Unfortunately, no published specifications, Federal construction guidelines, or security manuals exist which provide standards for increasing penetration delay against the threat of a determined adversary using simple tools or against forcible entry by ramming with a vehicle. This section discusses access doors which are used for entry by vehicles such as trucks, automobiles, and commercial vans, etc.

Use of Vehicle Access Doors

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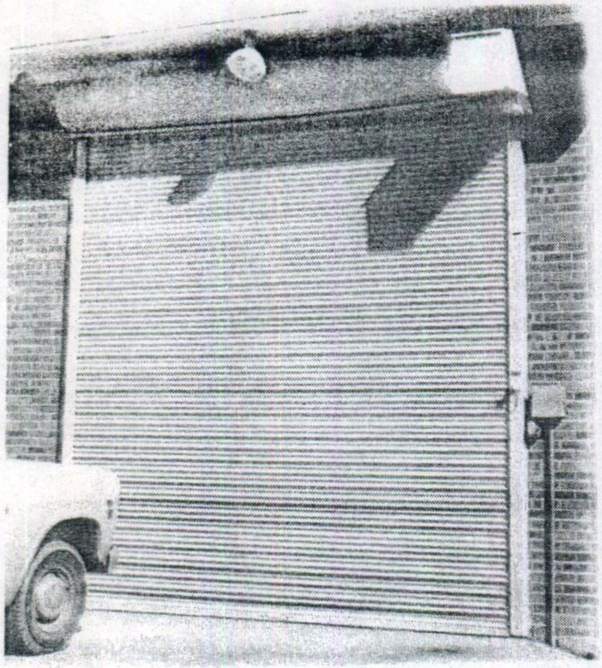

Figure 6-6. Corrugated Steel Roll-Up Door

Careful consideration should be given to eliminating vehicle doorways wherever possible.

Vulnerability

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b3

TABLE 6-1

Penetration Test Results for Corrugated Steel Roll-up Doors for Vehicle Doorways

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Upgrading Vehicle Access Doors

For those cases in which vehicle access doors cannot be eliminated, security considerations involve more than just enhancing the door design by increasing its capability to absorb energy. The total door installation, including fittings, locks, and hardware, must be considered. The siting of the doorway, its orientation, and its function are also important factors.

Hand-Tool Attack

Doorways can be designed with multiple doors to form airlocks which control vehicle and personnel entry. Multiple doors could be used to significantly increase penetration time. Subsequent doors in the series would have to be attacked with tools lifted through the opening in each door and used in the confined space between the doors.

Combinations of doors can also be used to increase penetration time. A double swing door located adjacent to and inside a roll-up door would complicate penetration by requiring the repetitive use of hand, power, and thermal tools. Steel plate doors, which can be used to replace corrugated roll-up doors, offer more penetration resistance to surface attack with cutting thermal tools; however, the hinges, lock, and frame must also provide the same resistance. Replacing corrugated steel roll-up doors with steel plate doors (see Figure 6-9) similar to igloo doors is a feasible upgrade.

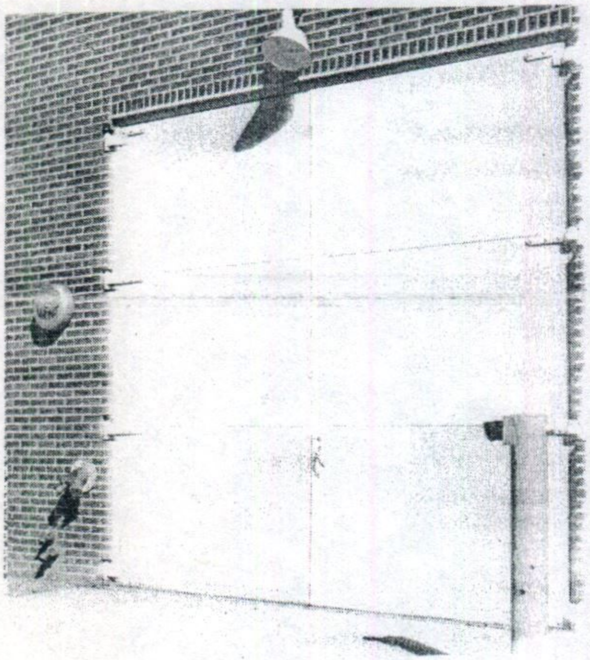

Figure 6-9. Steel Plate Doors

These upgrades may also be effective against ramming attacks. Again, the precept applies that the upgrade does not need to exceed the penetration resistance of the host structure and, conversely, unless the doorway can be upgraded, it may not be cost-effective to upgrade the building structure.

Vehicle Ramming Attack

High-energy impact attempts can be deterred by the use of a "King Tut Block," a single massive concrete block which is placed in front of or behind a door by a fork truck or crane. Siting considerations are often a more practical upgrade option than the addition of steel and armor to the door itself. High-energy vehicle impact can be prevented by imposing controls on vehicle approach speeds. Long straight approaches can be avoided in favor of right-angle turns or sharp curves. Also, vehicles can be parked in the driveway in front of existing doors. Reducing the impact velocity is an effective upgrade because impact energy is a function of the square of the speed of the vehicle. Crash beams can be installed to protect the door from ramming by forcing vehicles to stop before entry. Crash beams are simple in principle and can be custom designed for a variety of installations. Obviously a crash beam is not effective against hand-tool attack, but it may serve to prevent the close approach of a vehicle and thus force the transport of attack tools by hand over longer distances, increasing total time. An example of a crash beam is shown in Figure 6-10. Loading docks protect vehicle access doors from ramming. Also, vehicle access door installations can be enhanced against ramming by the provision of thresholds in the form of trenches, slots, or holes which engage dead bolt spikes.

Figure 6-10. Vehicle Crash Beam

Several concepts which have been tested for other applications could be used for upgrading vehicle access doors. Rubber tires could be installed directly behind an outer vehicle access door. Also, a rubber door clad with sheet metal could be used to resist impact penetration by a vehicle. A redwood core could be added to a panel door to increase thermal tool penetration delay. The increased weight also requires installation of heavier hardware, which also enhances resistance to hand tools and vehicles. A redwood core does not delay penetration attacks which use explosives. A door could be designed of alternately laid steel channels welded together and clad in thin sheet metal to provide greater penetration resistance. Other concepts, such as removable ramps across ditches or a road span which is lowered and raised on a hydraulic lift (drawbridges) could be developed for special applications.

Special Doors

Several doors have been manufactured which are resistant to most types of penetration, whether from malevolent attack or natural catastrophe. The 11-ton missile-resistant door shown in Figure 6-11 is one of many used by nuclear powerplants to protect against impact, earthquake, or tornado. It is designed to withstand the impact of a vehicle traveling at 60 mi/h.

Massive doors have been designed, including motorized plug doors (see Figure 6-12), which are 5 feet thick and weigh up to 45 tons. In effect, these massive doors are variations on the "King Tut Block" concept. These doors can also provide increased penetration delay against hand-tool, ramming, and explosives attacks.

Conclusions

Because of their great vulnerability to ramming attack and their low penetration resistance to hand-tool or explosives attacks, commonly used vehicle access doors may require upgrading.

IGLOO DOORS

Igloo door designs vary in size, shape, and function. Door thickness may vary from a single sheet of ¼-inch-thick steel to a 6-inch double-face design, depending on the nature of the storage and the site. These doors are frequently secured with a padlock and hasps. Igloo designs have evolved from World War II munitions storage depot structures, in which safety of personnel and blast protection were major considerations. In the years since World War II, upgrading these doors has consisted mainly of using improved locking mechanisms and welded hinge pins. Figure 6-13 presents estimated penetration time ranges for typical igloo doors.

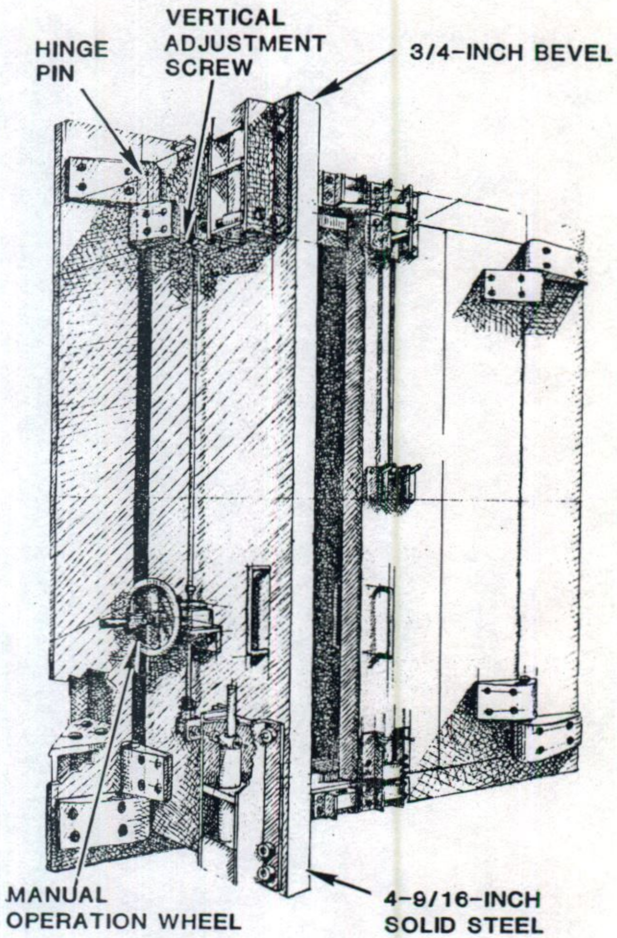

Figure 6-11. Missile Resistant Door (11-ton)

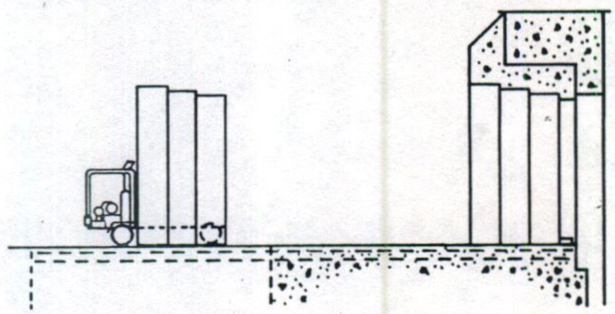

Figure 6-12. Motorized Plug Door (45-ton)

Figure 6-13. Penetration Times for Igloo Doors

Attack Modes

Door Faces

b3

Hinges

b3

Padlocks

b3

For additional information on locks, see Chapter 14: "Locks."

Hasps

b3

Conclusions

b3

Improved Design Concepts

Redwood Cores and Nails

b3

Passive Dead Bolts

Hinge vulnerability can be decreased by the provision of a bar dead bolt to hold the door within is frame in spite of hinge removal. If the door cannot be modified to accept this type of dead bolt, a heavy Z-strip can be added to the rear face to overlap the door frame or a vertical bar can be welded to the frame (see Figure 6-14).

Locks and Locking Systems

Replacing padlocks with recessed high-security cylinder locks and improved locking mechanisms or multiple dead bolts are methods of increasing the penetration delay time afforded by an igloo door (see Figure 6-15). However, if padlock replacement is not feasible, the use of high-security padlocks and hasps would provide a minimum upgrade.

Concrete ("King Tut") Blocks

Although not a new idea, concrete blocks are a very effective method of sealing off an igloo entrance. A large concrete block could be placed in front of igloo doors by a forklift that subsequently is removed from the area. The block is either placed over a protruding, upright I-beam which is inserted in a concrete pad in front of the doors or is contained between upright posts. This configuration provides a very effective "padlock" (see Figure 6-16).

VAULT DOORS

Vault doors are usually classified according to the thickness of solid steel in the door. Security vault doors are classified as 1, 3, 4, 5R, 6R, 9R, and 10R, with 10R indicating the greatest thickness (9½ inches).

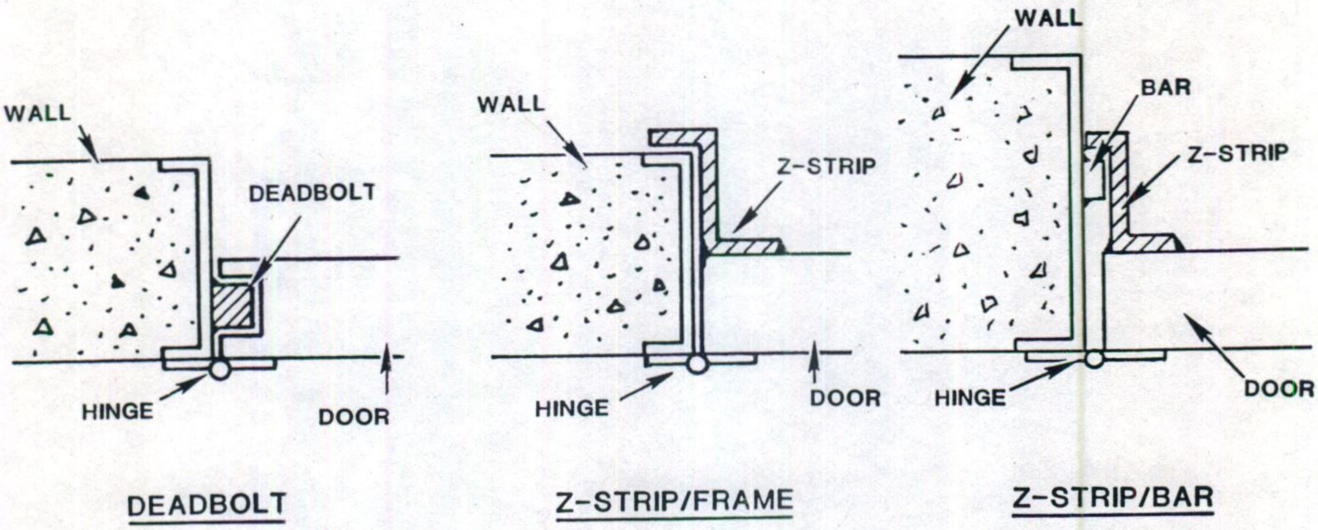

Figure 6-14. Hinge Upgrades for Igloo Doors

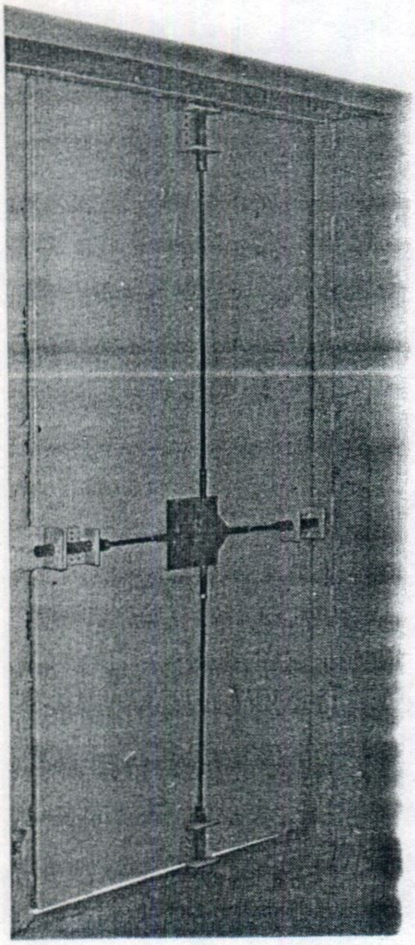

Figure 6-15. Multiple Dead Bolt Locking System

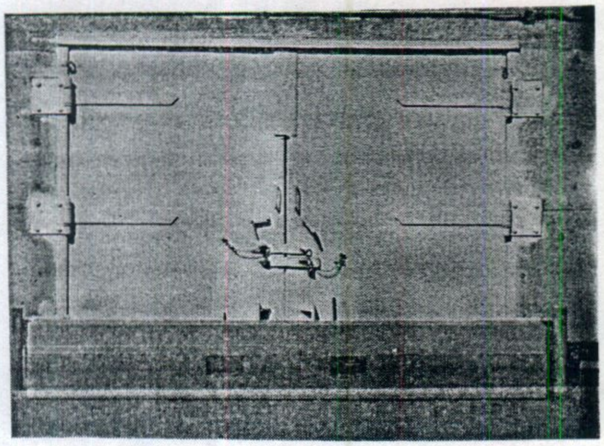

Figure 6-16. Concrete "King Tut" Block

Classifications 11, 12, and 13 indicate recommended bank vault doors. Mercantile vault doors are classified as B, C, E, and G; these rankings correspond to classifications 1, 3, and 4 for security vault doors. The "Insurance Services Office" standards and the "Bank Protection Act" requirements set the comparative ratings for vault doors as well as for other vault construction features. Only the Class 5 vault door has been evaluated by Sandia.

Class 5 Vault Doors

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Other types of vault doors, such as the lightweight mercantile vault door, the heavy bank vault door, etc., may also be suitable for selected security purposes and may offer significant penetration resistance for respective threats. However, as yet, no penetration times for these doors have been established.

Locking Mechanisms

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Other locking mechanisms are available with additional features such as automatic dead bolts that are activated by drilling or by thermal or explosives penetration attempts, time locks, wedge locking bars, and locking thresholds. These locking mechanisms will require evaluation before improvements in delay resistance can be established.

Improved Design Concepts

Existing vaults usually consist of a hinged steel vault door mounted in a reinforced concrete structure. Penetration times with hand, power, and thermal tools are usually less for a vault door than for the walls, floor, or ceiling of the vault. Because of the greater penetration delay time it affords, a reinforced concrete door the same thickness as the surrounding structure could replace a steel vault door to balance the overall penetration resistance of a vault.

In order to evaluate the balanced design concept, a full-scale steelcrete vault door[1] mockup has been constructed at Sandia (see Figure 6-17). The mockup consists of a 24-inch-thick reinforced concrete door of the same construction as the surrounding structure. A multiple application coded switch (MACS) controller located outside the vault controls unlocking of the door. A unique blade locking mechanism and the MACS itself are both located in a less vulnerable position inside the vault (see Figure 6-18). The steelcrete door is suspended by trolleys on an overhead inclined I-beam.

Figure 6-17. Vault Door with MACS Controller (Outside)

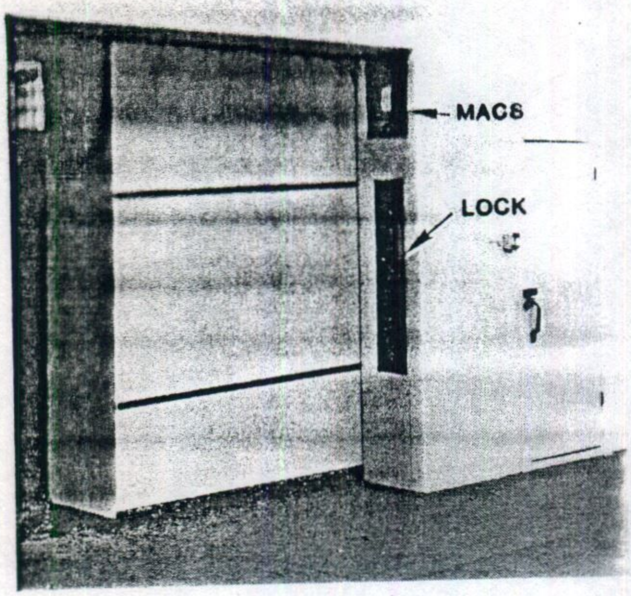

Figure 6-18. Vault Door with MACS (Inside)

A hydraulic system controlled by a manual valve lever is used to open or close the door. When the door is open, it is monitored remotely by a security guard and can be closed by the guard if he detects an emergency situation. The door then closes by gravity, without the use of commercial power, and locks automatically when the door is fully closed. After an emergency lockup, a waiting period ensues which prevents anyone from immediately unlocking the vault.

Because the door is constructed of the same material as the surrounding structure and because the unlocking mechanism is located in a protected position inside the vault, the overall vault design is considered to be balanced since most attacks to either the door, lock, or structure would require the same amount of penetration time for hand, power, or thermal tools or explosives.

REFERENCE

1. M. R. Kodlick, *Barrier Technology: Vault Door Concept and Mockup*, SAND80-0998 (Albuquerque: Sandia National Laboratories, September 1980).

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Standard PO and AEC Specifications, Section 8B: "Steel Doors and Door Frames—Pedestrian Type." 1974.

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Chapter 7

CHAPTER 7

WINDOWS

INTRODUCTION

Windows provide only minimal penetration delay to adversaries and require enhancement to provide significant penetration resistance. The location of the window affects the upgrading required. Windows should follow the balanced design principle so that they will not be the weak link in a barrier system. This chapter describes frames, glazing materials, and protective coverings, as well as other suggestions for improving window penetration delay times.

FRAMES

Frames and sashes are classified as fixed or operable, casement, awning, sliding, etc. The size of the glazed opening varies according to the sash dimensions and the muntin-mullion configuration. These two elements of the frame may be the most vulnerable parts of a window, especially when the glazing material is of the laminated security or armor type.

The strength and weight of the frame material of a window vary widely with class of window and manufacturer. Some manufacturers fabricate a "security sash": however, this term can be misleading since the frame material is not hardened.

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However, several special window frames are manufactured which contain concealed materials that resist cutting tools. The frames and sashes are manufactured from stainless steel, steel, aluminum, and wood, with aluminum and steel being the most common materials. If a window is operable, the locking mechanism may constitute a weak link, and, if forced, this window can be opened.

The position and operation of the locking mechanism of a window vary with type and manufacturer. The mechanism should be located so that it is not readily accessible from the exterior. The installation of more substantial locking devices or fixed windows could be considered as possible upgrade options.

Frame attachment to the structure may be improved by the use of additional or heavier fasteners or by welding the frame fin, but these techniques may not affect the delay time unless additional upgrades are made to the glazing materials and/or protective coverings.

GLAZING MATERIALS

Glass and plastics are the two most commonly used types of glazing materials.

Glass

Glass glazing materials include standard, tempered, wire, and laminated glass. These types of glass provide a barrier to the elements but will not provide significant delay times (Figure 7-1).

Standard Glass

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Where a higher level of penetration resistance is

Figure 7-1. Comparative Window Penetration Times required, thick security glass can be used. In addition, standard glazing materials are often upgraded with a protective grill of expanded steel mesh or other forms of metal grills.

Tempered Glass

Tempered glass is formed by the reheating and sudden cooling of a base glass. Although tempering greatly increases the mechanical strength and thermal stress characteristics of the glass, it can still be easily broken with moderate force.

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Wire Glass

The primary use of wire glass is in fire doors and fire windows as required by the National Bureau of Fire Underwriters (NBFU) codes; most types of wire glass are Underwriters Laboratories (UL) listed for this purpose. The ¼-inch-thick material is fabricated with diamond, square, or hexagonal wire patterns; minimum wire size is No. 85 ASW gauge. Wire glass which is nontransparent can also be used as a glazing material.

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Laminated Glass

Laminated glass is manufactured as a "safety and security glass"; however, not all types of laminated glass are recommended by the manufacturers for use in security areas. Laminated glass is composed of two or more panes of annealed float, sheet, or plate glass bonded to a layer or layers of polyvinyl butyral plastic and ranges in thickness from 0.050 to 0.090 inch. The thickness of the composites ranges from 9/32 to 13/16 inch, depending upon the manufacturer.

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Security glass is not transparent armor. It is simply more resistant than standard glass to forcible penetration.

Plastics

Transparent plastics (acrylics and polycarbonates) can be used as substitutes for most glass; however, some are combustible and their use is restricted by fire codes.

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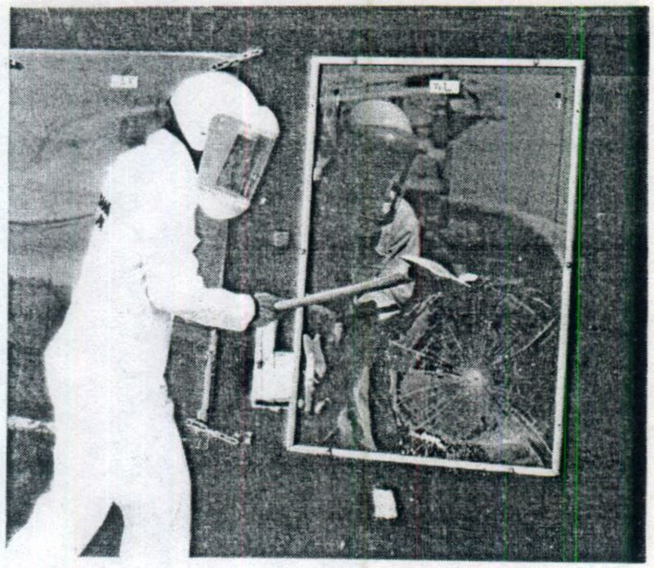

Figure 7-2. Penetration of Laminated Glass with Fire Axe

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PROTECTION

Increased penetration resistance of a window may be achieved by the installation of protective coverings, such as grills, bars, expanded-metal mesh, or screens.

Grills

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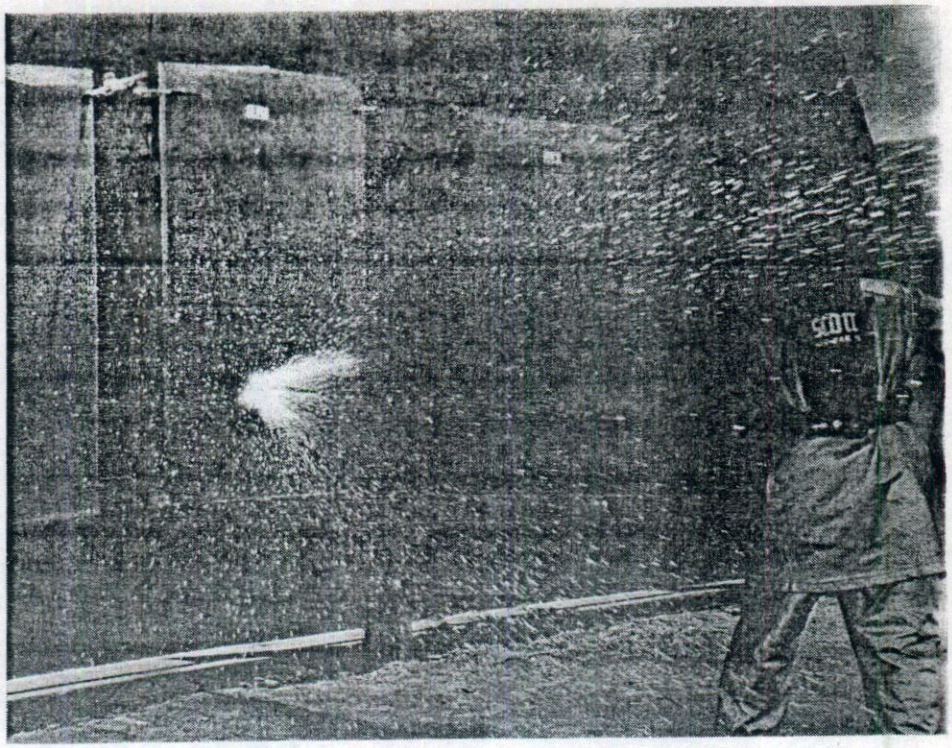

Figure 7-3. Burn Bar Attack against Acrylic Plastic

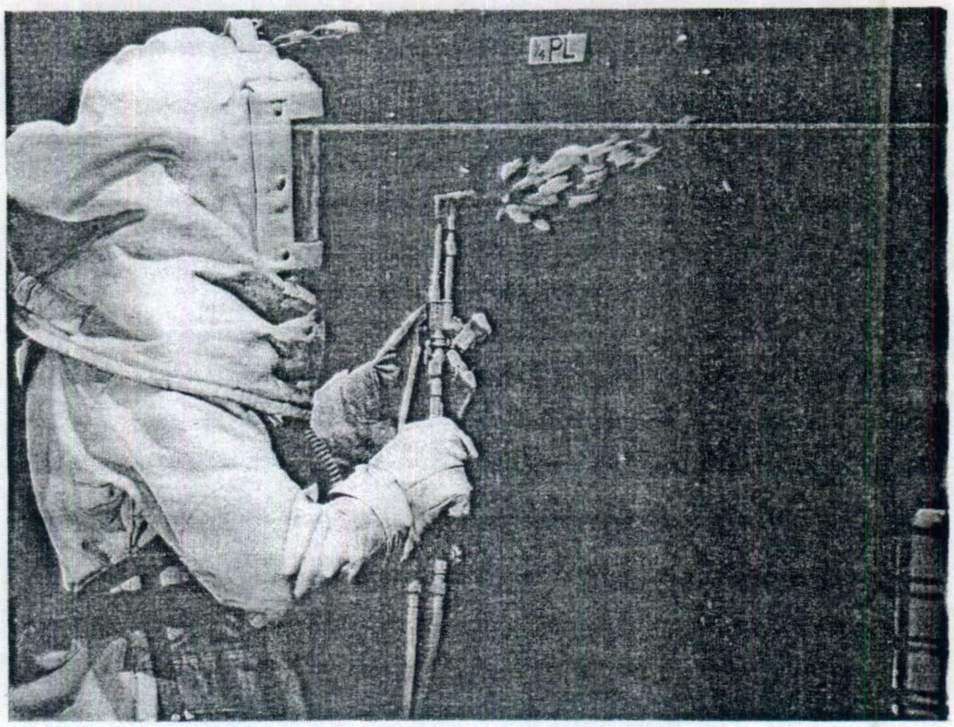

Figure 7-4. Oxyacetylene Torch Attack against Acrylic Plastic

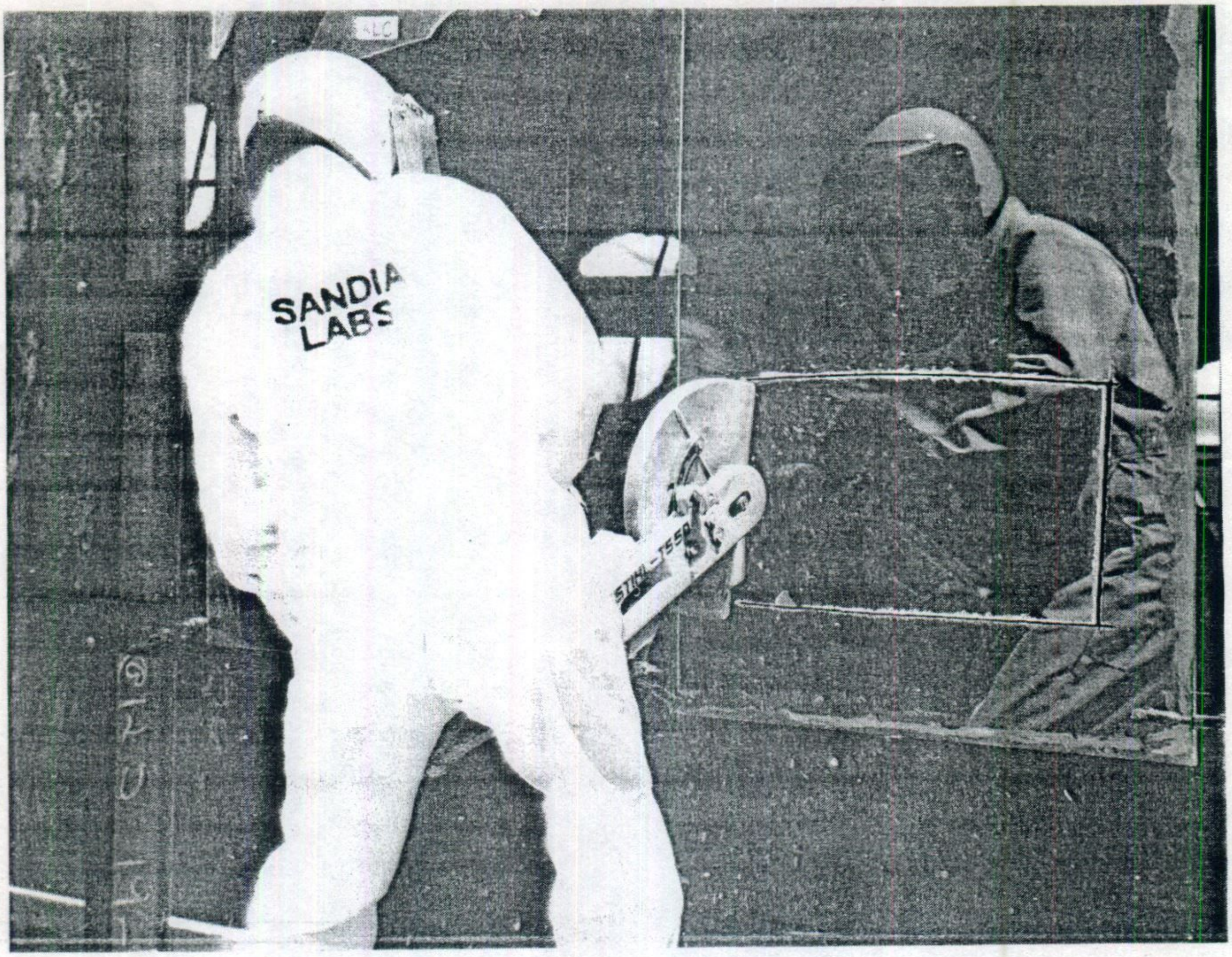

Figure 7-5. Penetration of Plastic Panel with Demolition Saw

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The protective grill should be adequately anchored to the wall to ensure that the time required to remove it and the level of difficulty involved are equal to or greater than the wall penetration time and difficulty.

Mesh

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Screens

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[redacted]

For complete information on grills, bars, mesh, and screens, see Chapter "Utility Ports."

When protective coverings are applied, care must be taken to ensure that their attachments to the structure do not provide a lower penetration delay. The selection of glazing material, without enhancement, may not provide any significant increase in penetration time unless the selection is thick security glass or transparent armor.

CONCLUSIONS

[redacted] The degree of improvement should be dictated by the balanced design concept. With the proper selection of enhancements (protective coverings, grills, mesh), different glazing material, or methods of frame attachment, the delay time of windows may approach the delay time of doors or even walls for some threats.

An option that may be considered in future designs for new buildings could be the use of smaller than man-sized windows. Also, windows could be removed from existing structures; this would allow the original window openings to be upgraded to the same penetration delay as the adjoining wall.

Comparative penetration times for some windows (with and without enhancements) are given in Figure 7-1. Values have been extracted from the Barrier Data Base included in Chapter 15: "Penetration Rates and Data Base."

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CHAPTER 8

UTILITY PORTS

INTRODUCTION

In addition to doors and windows, industrial facilities have many unattended structural openings, such as ventilating ducts, utility tunnels, and service openings, that can be used as intrusion paths by adversaries. Few existing structural openings would delay a determined adversary for very long, especially if the openings are designed to provide easy access for maintenance. These openings can function as a concealed pathway and, therefore, should be barricaded and possibly alarmed.

The term utility port is used in this discussion to include all types of unattended framed openings other than doors and windows. Included are such features as ducts, air shafts, tunnels, crawl spaces, sewers, drains, water inlets, areaways, conveyor openings, trap doors, skylights, roof access hatches, filter banks, diffusers, louvers and registers, attics and false ceilings, dumb waiters, elevator shafts, pass-throughs, chimneys, rafter walkways, coal and ash chutes, roof vents, manholes, cupolas, equipment penthouses, and exhaust fans. Often these openings contain grills installed for safety and ornamental reasons, which also function as insect and rodent barriers. These openings may provide very little security. This section examines some of these elements, presents results of evaluation tests, and contains suggestions for improving the barrier value of utility ports.

TYPES OF UTILITY PORTS

Electrical, Mechanical, and Service Passageways

Most tunnels used to link buildings are not protected. Access may be controlled only by lift-off covers or manholes which are not equipped with locking devices or interior barriers. An example of such a structure is shown in Figure 8-1.

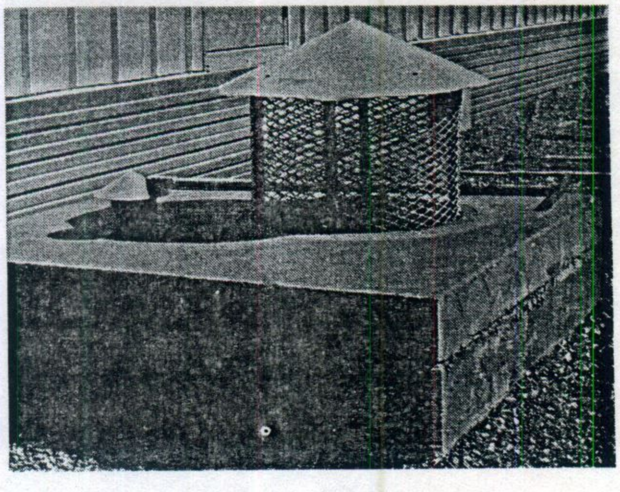

Figure 8-1. Steam Tunnel

Pipe chases are used inside buildings and are often quite congested; however, they still allow space for maintenance work. Some facilities have interconnecting vertical and horizontal chase systems which could provide adversary paths.

Pipe sleeves and cable trays are usually only large enough to permit pipes and cables to pass through a wall or floor.

Equipment penthouses, air supply fans, exhaust fans, gravity ventilators, in addition to sewers for storm and sanitary drainage, and manholes for electrical power and telephone cables may also provide an adversary path.

Heating, Ventilating, and Air Conditioning Systems (HVAC)

Ducts associated with heating, ventilating, and air conditioning systems could provide an adversary path. Gravity ventilating ducts similar to those used in storage igloos could also be weak links in a security system.

PENETRATION TESTS

Existing Ducts

Almost all site facilities have HVAC duct systems. Structures associated with these systems are composed predominantly of sheet metal which is vulnerable to attack with simple hand tools. To establish penetration times, 25 attack tests were made on 15 duct arrays. These tests consisted of cutting through the ducts and crawling and climbing through ducts of different sizes, gauges, and orientation. Male volunteers of at least average height and weight were used for all tests.

Crawl-Through

Crawl-through tests were made on ducts of five different sizes. The smallest duct, 12 inches square, was too small to allow entry. Ducts which were greater than 18 by 36 inches were merely inconvenient and had no meaningful delay value. Crawling rates or various duct sizes are given in Table 8-1.

Climbing

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TABLE 8-1

Crawl-Through Rate for Various Size Ducts[1]

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One 18- by 18-inch by 16-foot duct and one 24- by 24-inch by 20-foot duct were tested in this manner. Figure 8-2 illustrates portions of these climbing tests. Table 8-2 lists penetration times and rates for the climbing tests.

Figure 8-2. Climbing Vertical Duct

TABLE 8-2

Summary of Duct Climbing Tests

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Cutting

Penetration tests were performed on several horizontal ducts by attackers who crawled into the ducts and exited the duct walls using various tools. Cutting rates for various attack modes were recorded; these data are included in Chapter 15: "Penetration Rates and Data Base."

Upgraded Ducts

Six tests were made on upgraded duct configurations. These configurations included ducts with interior grids, segmented ducts, and ducts with barbed tape liners.

Interior Grids

To upgrade the ducts, grids were installed in vertical and horizontal sections of the 18- by 18-inch ducts. These grids were fabricated from ½-inch diameter bars on 6-inch centers. This is a commonly used grid.

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Segmented Ducts

A 24- by 24-inch by 10-foot duct was constructed from four 12- by 12-inch duct sections. These ducts could not be penetrated when attacked with hand-operated metal cutters or with a portable torch; the tests were stopped after approximately 10 minutes, with less than 10 inches of the 10 feet severed. Examples of attempts to penetrate segmented ducts are shown in Figure 8-5a,b.

Barbed Tape Liners

A simple way to increase penetration time is to install general purpose barbed tape obstacle (GPBTO) or barbed tape concertina (BTC) inside the ductwork.

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cannot be used, barbed tape bands or ribbon liners could be riveted to the walls (see Figure 8-6).

Wire Mesh Screens

A series of attack tests on wire-mesh space screens was conducted to determine penetration time for existing grids. The results of these tests are used in the evaluation of proposed upgrades. Five sizes of screens were tested. The openings in the screens ranged in size from ⅝-inch square to 2¼ -inch square; the wire diameters ranged from 0.162 inch to ½ inch.

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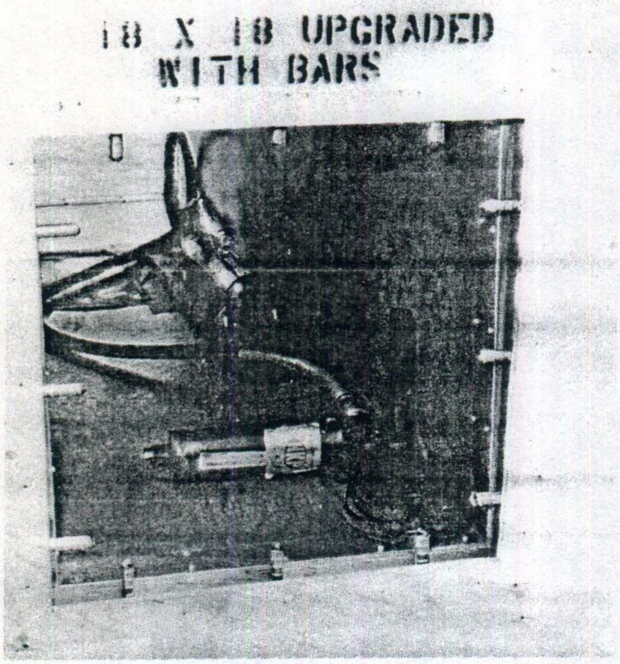
The test results are summarized in Table 8-3. A typical test panel is shown in Figure 8-7.

Cutting rates have been tabulated according to each tool used and each mesh size. These tables, which are included in Chapter 15: "Penetration Rates and Data Base," can be used for estimating the time required for cutting openings of various sizes, for comparing tool cutting speeds on the same grid, or for comparing penetration times for various grid sizes.



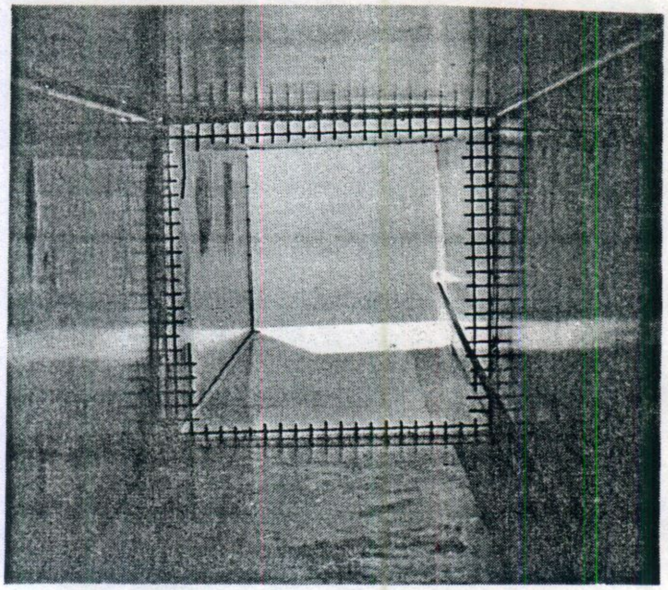


Figure 8-3. Attack with Hand-Operated Hydraulic Bolt-cutter

Figure 8-4. Vertical Duct Upgraded with Grid (Penetrated)

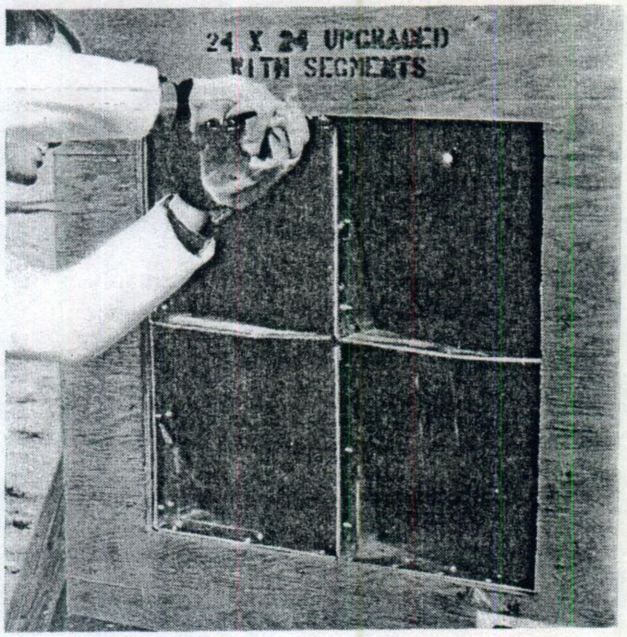


Figure 8-5a. Segmented Duct Upgrade Attack with Oxy-acetylene Torch

Figure 8-5b. Segmented Duct Upgrade Attack with Hand Metal Cutters

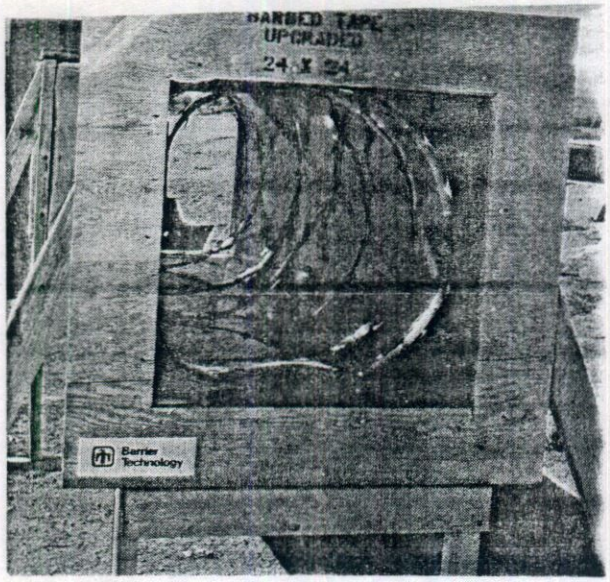


Figure 8-6a. Duct Upgraded with Barbed Tape Coils

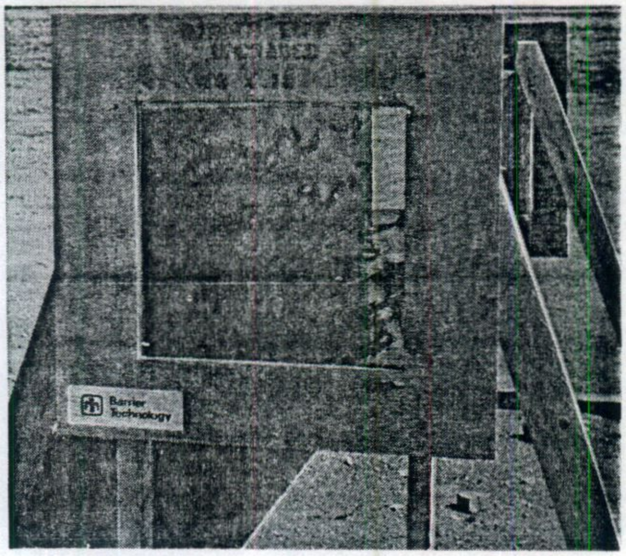


Figure 8-6b. Duct Upgraded with Barbed Tape Strips

TABLE 8-3

Summary of Wire Mesh Penetration Tests

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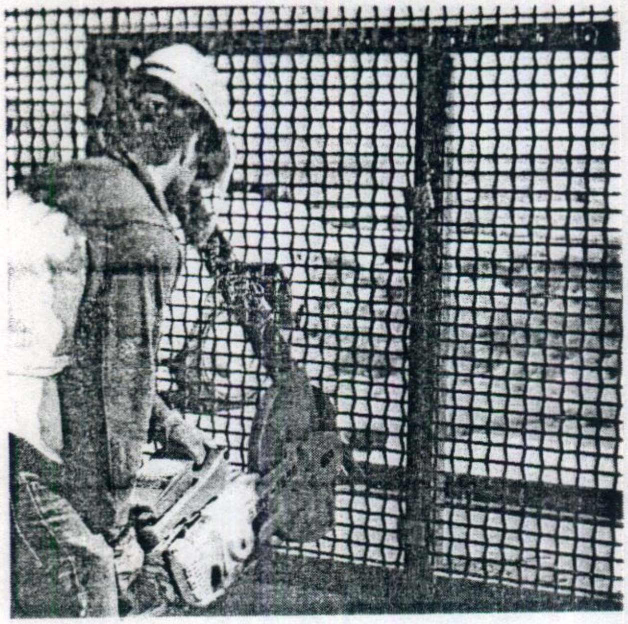


Figure 8-7. Demolition Saw Attack Test

Bar Cutting Rates

A series of bar cutting-rate tests was conducted on four diameters of mild steel bars using an oxygen lance, an oxyacetylene torch, and a hacksaw. The test racks were oriented to simulate wall (vertical), roof (overhead), and floor (underfoot) attack positions. The averages of these tests are shown in Table 8-4. The values shown in Table 8-4 can be used to estimate the penetration delay time of any grid when the bar size and spacing, location, and type of attack tool are known. Conversely, a grid can be designed to provide a specified penetration time based on the parameters of Table 8-4.

UPGRADING CONSIDERATIONS

One method of delaying entry to a facility through structural openings is to reduce the size of the opening to less than crawl-through size. A variety of locking grids and grates can be used to achieve this reduction. Grids and grates are usually constructed of steel mesh, expanded metal, bar stock, tubing, or jail bars. Perforated steel

TABLE 8-4

Average Cutting Rates for Low Carbon Steel Bars in Minutes per Cut

Bar Diameter (inch)	Oxygen Lance	Oxy-acetylene Torch	Hack Saw	Demolition Saw
¾	0.06	0.14	0.90	0.17
1	0.09	0.21	1.84	0.40
1-½	0.15	0.29	3.80	1.78
1-¾	0.19	0.39	5.48	3.95

plates, copper bars, stainless or hardened steel, and fiberglass may also be used. Woven wire is available in stainless steel, aluminum, brass, bronze, copper, monel metal, etc. The wire can be round, square, flat or crimped. The use of wire-mesh space screens affords a viable method for upgrading the barrier value of existing utility ports.

Bar placement is important in the construction of grids and grates. Weight is a limiting factor. If more steel can be placed in an adversary's path, the energy requirements for penetration and longer delay will be greater. Gratings can be designed with various shaped and sized openings (see Figure 8-8). Conventional ducts are usually rectangular or round. Narrow openings or a series of slots can perform the same function. An option that allows increased protection but does not significantly inhibit flow is the use of multiple small openings rather than a single large opening.

One effective method of upgrading sewers, culverts, and drains is to install tube liners or baffle plates (see Figure 8-9). Tube liners and baffle plates are available in an almost infinite variety of materials and dimensions and can be tailored to fit almost any installation. Multiple segments of liners and baffles can be emplaced at appropriate locations. The concept of using small-sized ducts

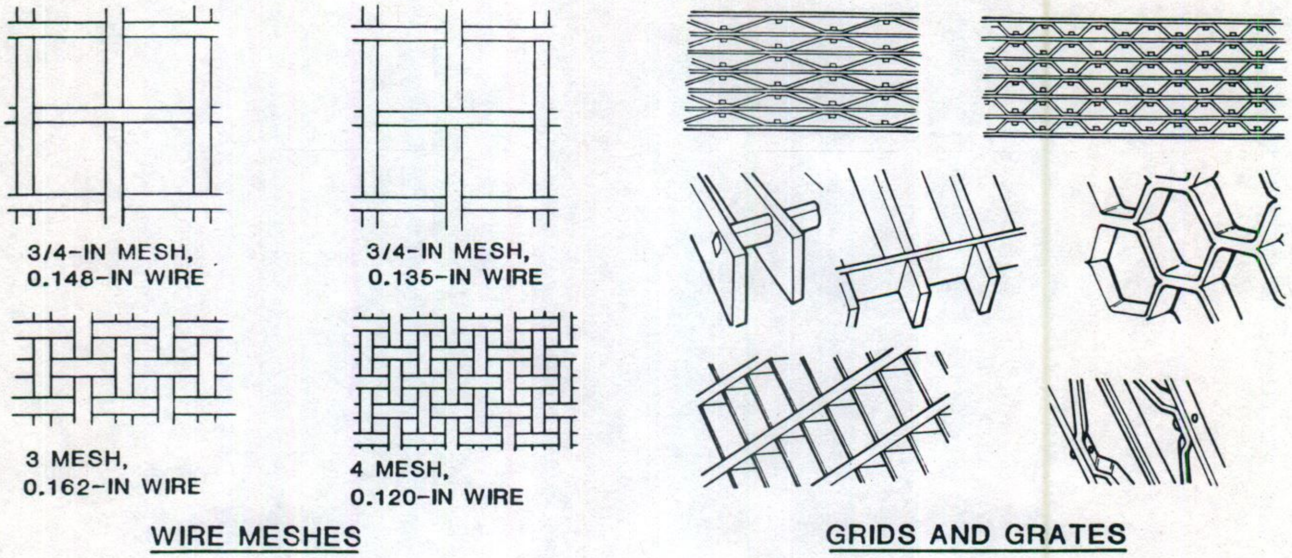


Figure 8-8. Wire Meshes, Grids, and Grates

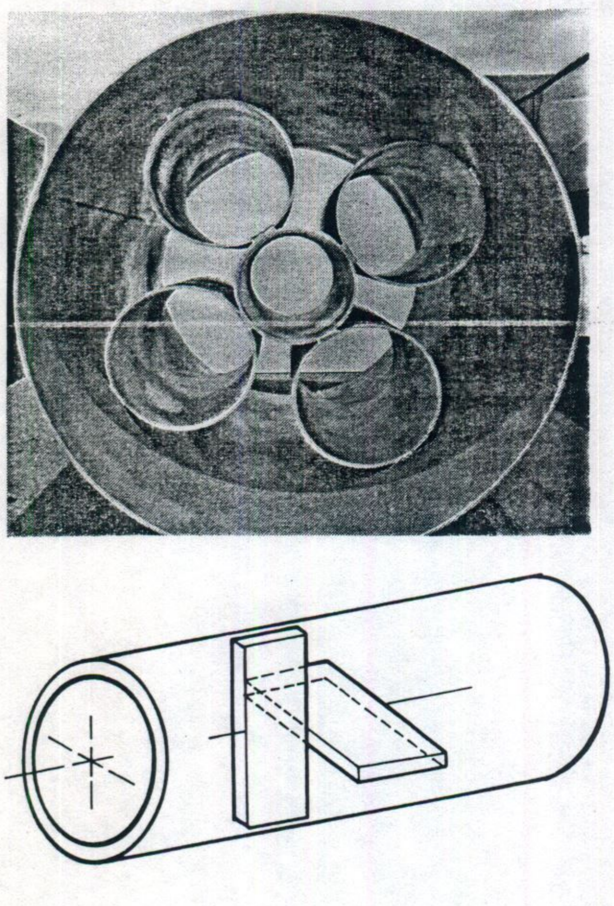


Figure 8-9. Sewer, Culvert, and Drain Upgrades

in combination allows almost infinite variations in materials and dimensions, has universal application, and offers many possibilities for custom upgrades. This upgrade provides a substantial barrier which is difficult to penetrate by external and internal attack. One viable upgrade option would be to place multiple-segment ducts at strategic locations. When properly used, segmented ducts are cost-effective and have little effect on air flow. The use of barbed tape to deter penetration is simple and cost-effective. A variety of configurations (lateral bands, coiled ribbon, and cross bands) permits custom installations to be upgraded with a minimum effect on duct system performance. Different upgrade techniques can be combined in various ways. For example, segmented ducts with lateral ribbons of barbed tape on each wall and with grids at appropriate spacings are difficult to penetrate. These concepts can be combined and installed in multiples in the same system. HVAC ducts are universally used and may make excellent adversary paths; however, they can be easily upgraded with heavy duty closures, grids, screens, grates, and barbed tape. If heavy diffusers or registers are attached with heavy bolts and grids are installed in series in the duct work with coils of GPBTO between them, the delay is cumulative.

Duct work can be improved by grids or other modifications which reduce the entry size or shape. Grids are available in a wide variety of wire diameters and opening sizes, facilitating custom installations for large openings such as air shafts, tunnels, sewers, culverts, ash chutes, and other unattended openings. Grids can be installed in multiples. Multiple grids of different sizes can impose tool weight requirements and logistic limitations that could deter an adversary from attempting forcible entry.

CONCLUSIONS

Utility ports constitute a potential weak link in a barrier system and may require enhancement to provide significant delay. Tunnels, manholes, roof and wall openings for equipment, and duct work can be enhanced by installing interior barriers or series of barriers.

REFERENCE

1. Joseph Crompton, "Penetration of Heating, Ventilating and Air Conditioning (HVAC) Ducts," SAND79-0336. (Albuquerque: Sandia Laboratories, to be published).

CHAPTER 9

VAULTS AND IGLOOS

INTRODUCTION

The concept that material deposited in a vault or an igloo is secure from theft can be misleading since vaults and igloos may be penetrated in a variety of ways if the adversary has access, time, and proper equipment.

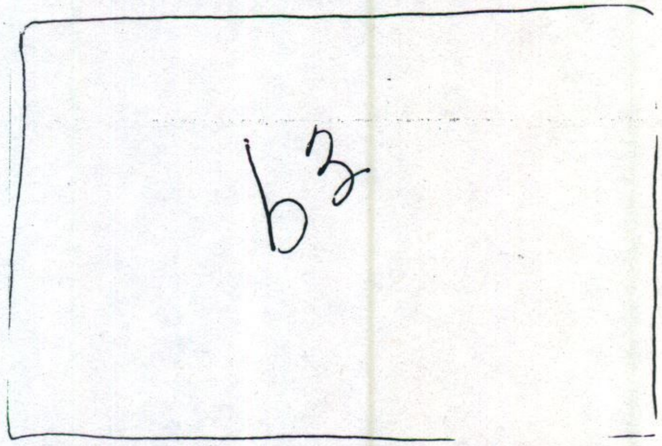
Vaults considered in this chapter are large walk-in types with either single-leaf or double-leaf doors and concrete and/or steel walls, floors, and ceilings. Usually they are located within a larger structure instead of being free standing. Igloos are usually considered as individual structures.

The term igloo describes a special-use building which is covered with earth overburden. Igloos are primarily arch-type structures of reinforced concrete or corrugated structural steel plate; the vertical end walls consist of reinforced concrete. The front wall extends above and beyond the sides, forming a barricade that retains the earth overburden (Figure 9-1). There have been a few conventional post and beam constructed igloos; these special-use igloos generally have a short roof span and the advantage of extra head height adjacent to the walls, which small arched structures do not permit.

This chapter discusses vaults and igloos as barriers with respect to their penetration resistance and methods of enhancement.

VAULTS

A vault is composed of four basic structural elements—floor, walls, roof, and door(s)—which should meet specific criteria for containment of material. In addition, some vaults require ventilation ducts which must be considered as potential entry paths for adversaries.



The Bank Protection Act of 1968 (revised 1973) and the Insurance Services Office have different standards for vault construction, specifically thickness of walls, roof, floors, and doors in seven classes with several different construction options for walls, roofs, and floors. In general, as the sensitivity of the vault contents increases, the resistance to penetration of walls, doors, and other elements should also increase.

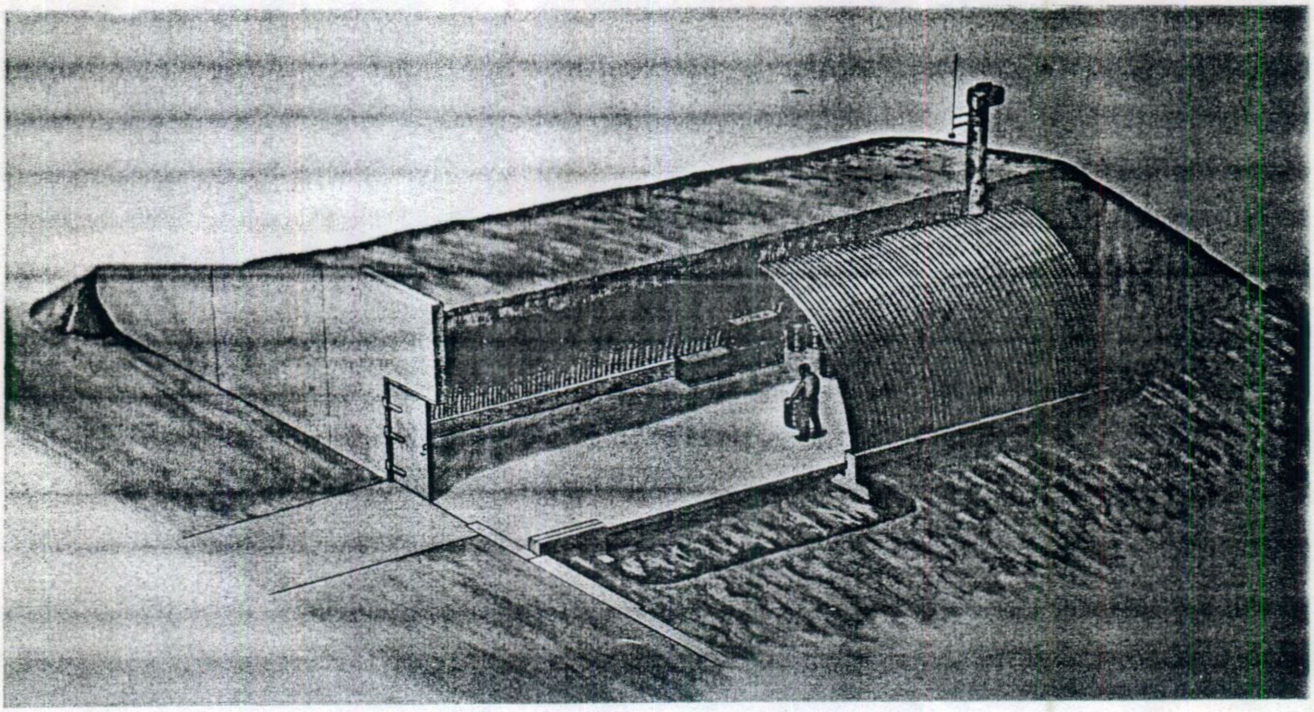


Figure 9-1. Conventional Storage Igloo; Sectional View Showing Overburden 2 to 3 Feet Deep

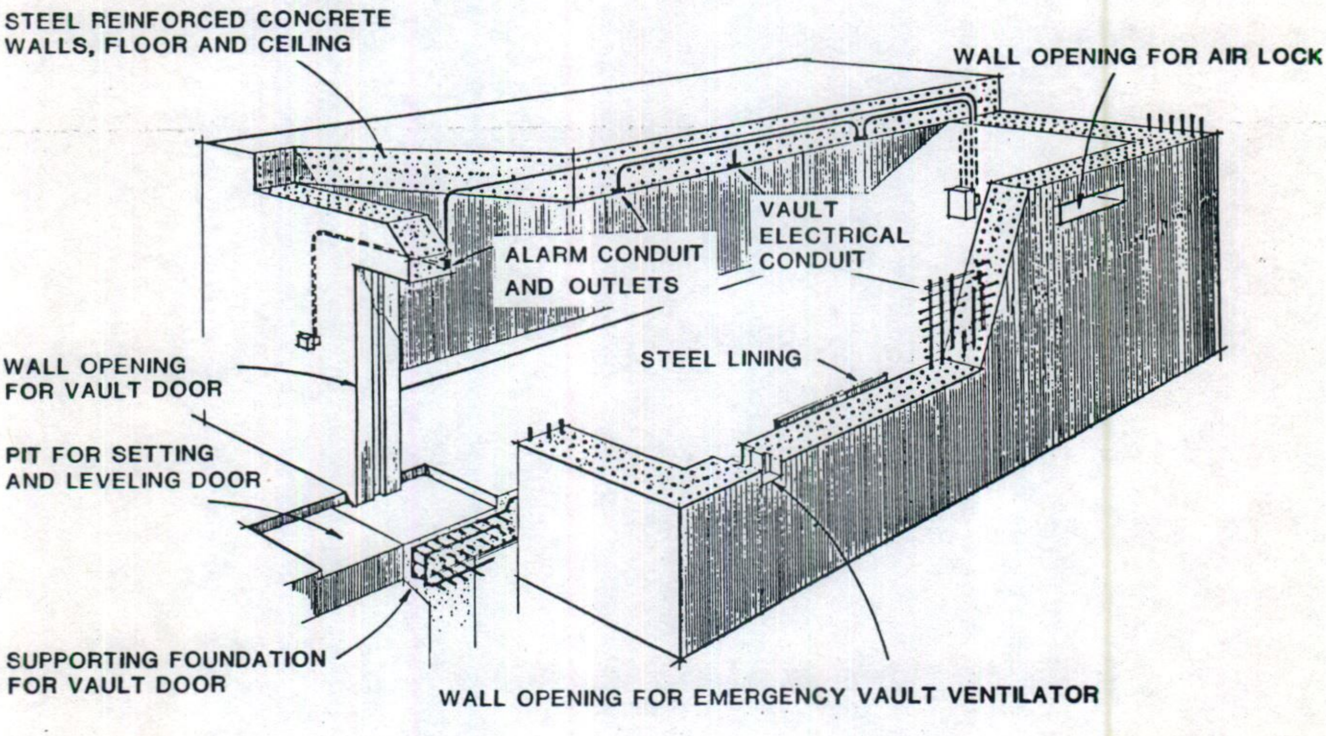


Figure 9-2. Vault Construction

TABLE 9-1

Vault Penetration Mean Times (minutes)

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The placement, type, size, and quantity of steel reinforcement in concrete can significantly affect penetration times for explosive attacks. Some vaults are constructed with standard deformed steel reinforcing bar or expanded steel bank vault mesh in a stacked placement. Some walls with this steel placement have been tested by explosives. Some of the explosive tests have indicated that the expanded steel bank vault mesh walls can be penetrated more quickly when significant amounts of explosives are used.

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The staggered placement of either type of steel reinforcement, as recommended by the banking and insurance industries, has not been fully evaluated.

Chapter 4: "Walls" contains extensive information on walls, including steel walls, reinforced concrete walls of various thicknesses and steel placements (deformed rebar and expanded steel bank vault mesh, 3.63 lb/ft^2), fibrous concrete walls, composite walls, stand-off walls, and others, many of which have been tested and for which penetration times have been established. Comparative penetration tables are presented in Chapter 4, and specific wall penetration times are given in Chapter 15: "Penetration Rates and Data Base."

Location

The location of a vault within a building could be a factor in determining its penetration resistance, e.g., being placed on an exterior wall versus emplacement completely within the building. An exterior wall location may provide an adversary with a stealthy penetration path or permit the use of explosives on the wall or roof with the same impunity with which he could attack an exterior building wall. When the vault is emplaced within the building, the adversary may be reluctant to use explosives or be limited in the amount he could detonate without causing a structural building failure from the resulting overpressure and/or shrapnel.

Openings

The openings in a vault, vault door(s), ventilation ducts, etc. may a weak point in an otherwise hardened structure. However, openings are necessary for access and utility purposes. They should be considered in the overall penetration resistance of the vault. Penetration times and enhancement concepts for vault doors are discussed. In Chapter 6: "Doors;" the same information for ventilation ducts and utility ports is discussed in Chapter 8: "Utility Ports."

Enhancements and Advanced Concepts

Some existing vaults and/or vault doors may not provide the penetration delay time considered necessary for certain security systems. The balanced design concept should be followed, i.e., avoiding the overdesign of one component, but at the same time not offering an adversary another weak part for penetration. It may not be effective to improve the vault structure and not improve the vault door(s). Conversely, to replace a 3-minute door with a bank-vault-type door at great expense may be an improvement for the door itself but would not increase the resistance of the overall structure.

Improvements to existing doors and advanced concepts are discussed in Chapter 6.

b3

The use of a vestibule with a second vault door, in which only one door at a time would be open, could be considered (Figure 9-3). The vestibule concept could be used with one of the dispensable deterrents for increased penetration resistance.

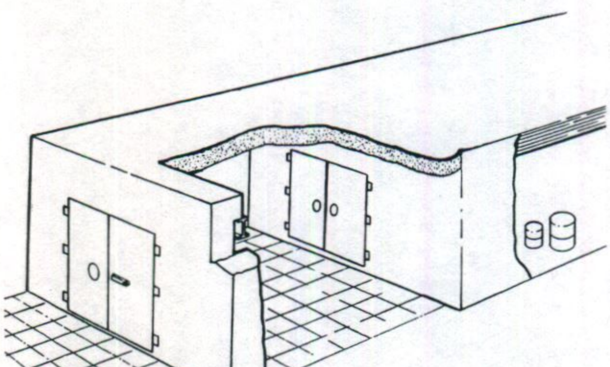


Figure 9-3. Cutaway View of Vault with Vestibule Construction

Walls (Structure)

The vault structure may be improved in resistance by several methods, such as the installation of a steel liner to form a sandwich wall.

b3

When the vault structure has exterior wall and roof surfaces, the possible use of some type of overburden could be considered; the amount is limited by the structural design. In addition, the overburden could be enhanced by soil cement, crushed automobile bodies, etc., to increase the penetration time. Overburden is discussed in Chapter 10: "Earth Cover and Overburden."

There are wall concepts such as (1) composite walls, including ceramic materials; (2) the use of different aggregate materials for concrete, such as lead shot; and (3) ceramic balls for increased resistance to cutting and thermal tools. Concepts are also being evaluated for energy absorption, possibly to increase flexibility and thus reduce damage from explosives. Stand-off walls or cavity walls are being studied to determine their ability to absorb blast energy and to improve penetration resistance to thermal attacks. All these concepts could be applied to vaults.

Underground Vaults

An underground vault has a lot of merit. Several feet of reinforced concrete would surround the storage compartment, which would be encased in a floor. Access would be controlled by a coded locking mechanism with an electrical system to lock or close the vault when the facility is under attack. Figure 9-4 illustrates this concept. This type of vault could be installed in existing structures with the storage capacity altered as required. Figure 9-5 illustrates another below grade storage vault with added enhancements: hinged roof with rubble, vestibule, special doors, and a pneumatically operated barrier block to control entrance.

The aboveground vault, Figure 9-6, has many of the enhancements of the underground vault, except that a deep overburden has been used to resist penetration from above.

Intimate Container Vaults

A new concept for a storage vault is illustrated in Figure 9-7. The vault structure includes square- or round-shaped steel tubes covered with reinforced concrete. A specially designed lattice-type structure door is used to complete the enclosure. The item to be stored is fitted with two collars which have rollers on the bottom to facilitate insertion into a tube.

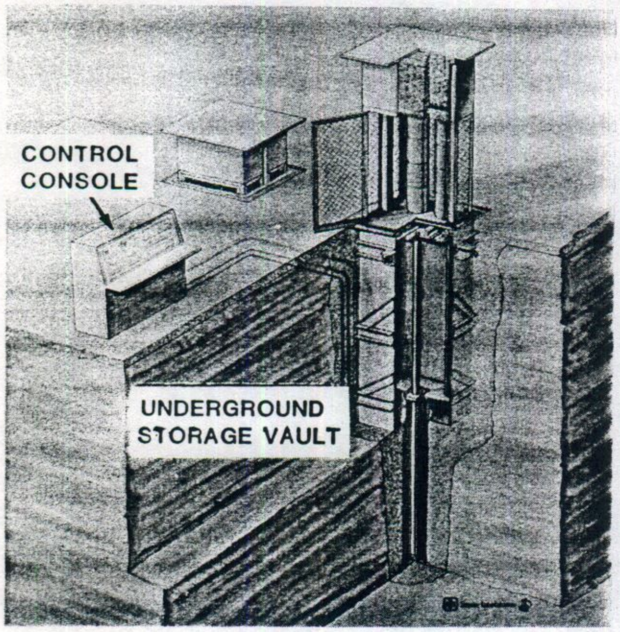


Figure 9-4. Underground Storage Vault

The concept of delay in removal of the stored item is based upon the intimacy of the store or collar with the tube liner. This feature forces the adversary to use more care (and time) to remove the contents. For the adversary to complete removal, an opening at least as large as the store must be produced in the side of the vault or the door. Achieving such an opening through the structure or door with hand, thermal, and/or hand-held power tools might require several hours. If a significant quantity of explosives is used at any point in the structure, the tube liner will likely buckle and bend around the store and the handling collar, effectively locking the store in place. When this occurs, the only possible way to completely remove the store is to dismantle the entire structure.

The access door and locking system, as contemplated, should have penetration resistance and delay equivalent to that of the structure. Explosives used against the door would not result in a "clean" hole large enough for removal and could buckle the tube liner.

One attack test was conducted against a single (as opposed to a multiple array, shown in Figure 9-7) vault structure.

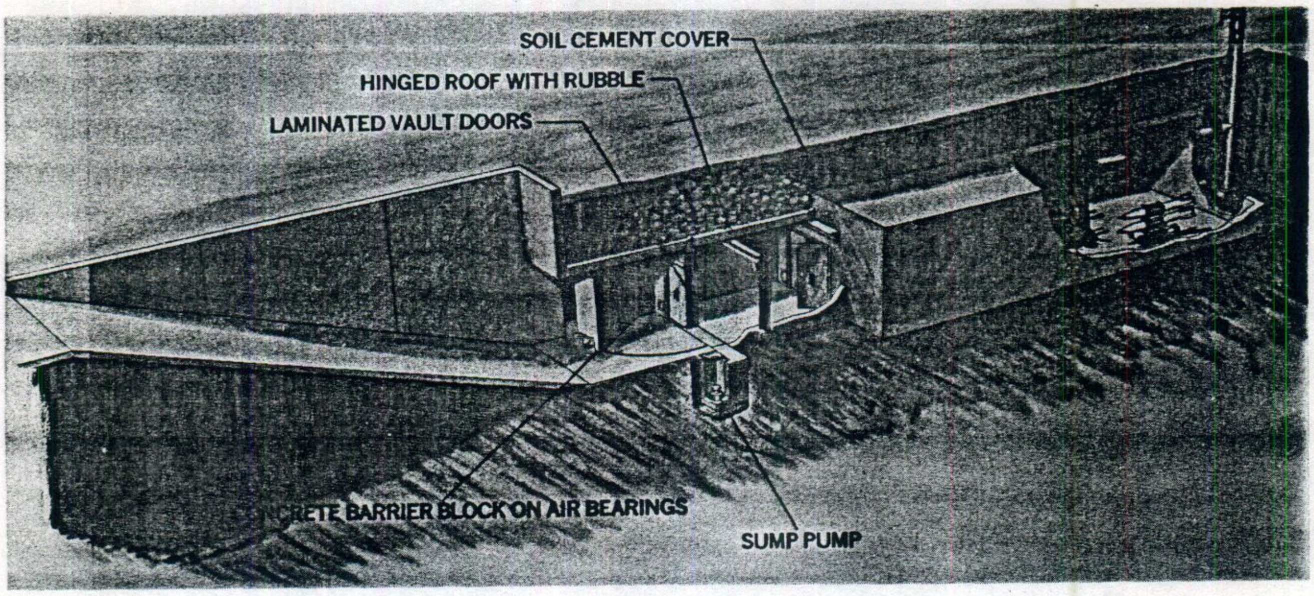


Figure 9-5. Below-Grade Storage Vault

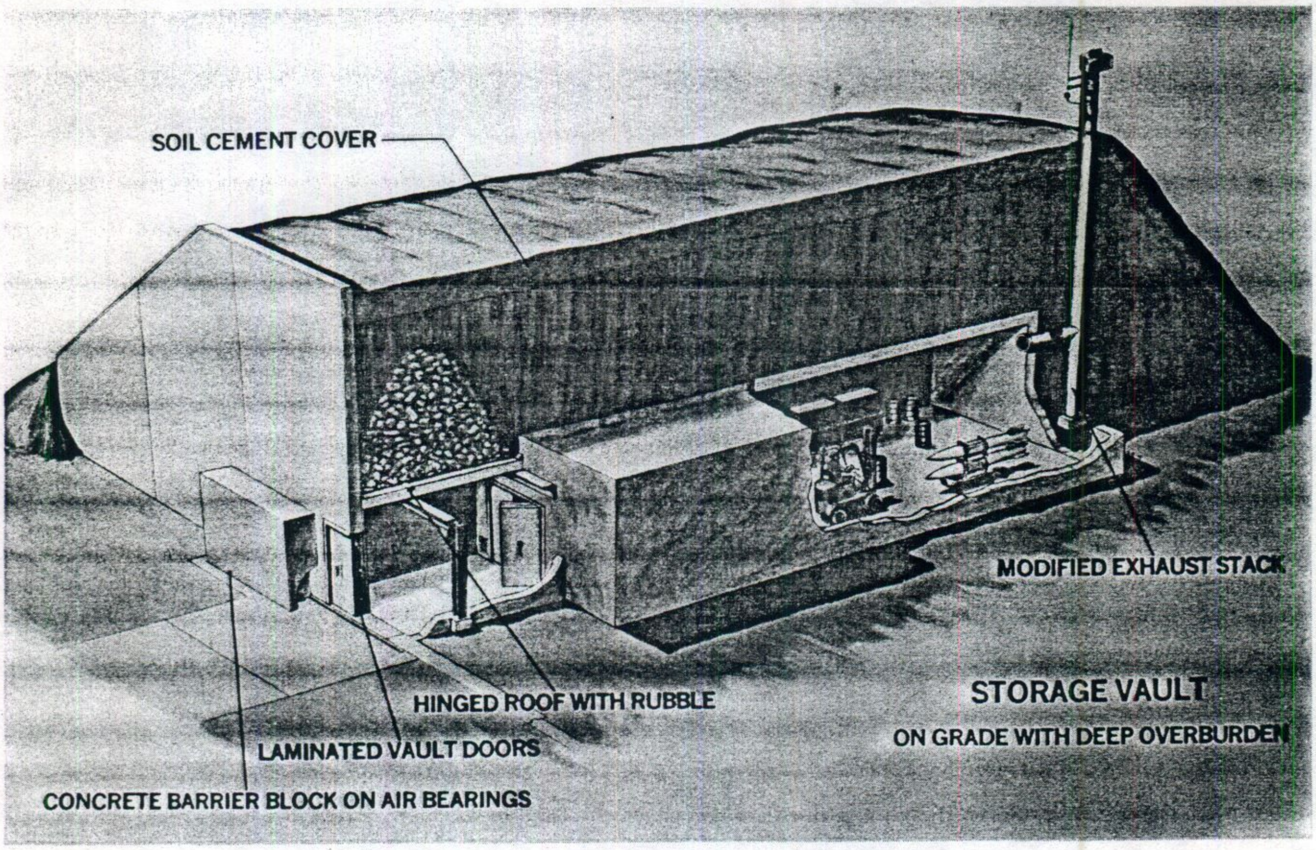


Figure 9-6. Storage Vault on Grade with Deep Overburden

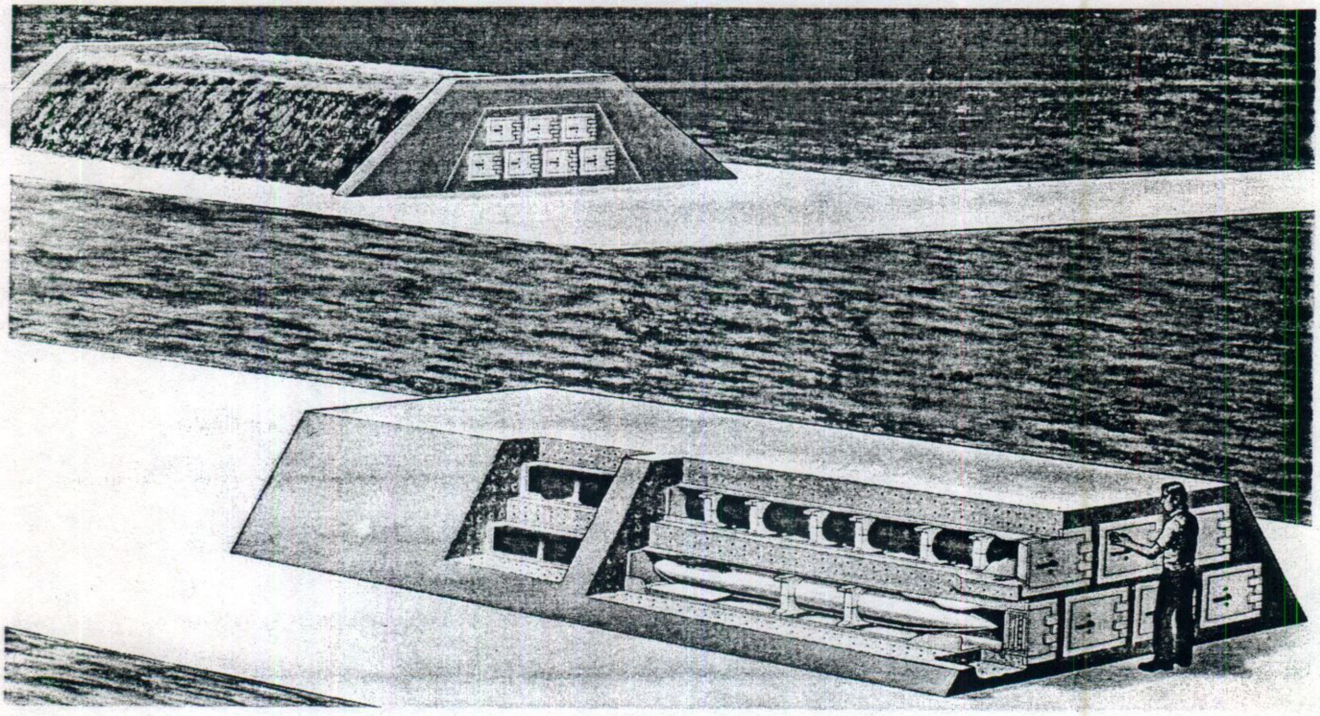


Figure 9-7. Intimate Container Vault

b3 This time would have been much greater (by hours) if a multiple array configuration had been attacked.

IGLOOS

Uses

The basic use of igloos is to store explosives. They are also used for the storage of weapons, hazardous assembly operations, nd radioactive laboratories and as mini-aircraft hangars.

These buildings were designed to reduce the chance of accidental chain-reacted detonations between structures and, concurrently, to provide better than average structural resistance to penetration. They may be compared to a windowless quonset. The component parts are functionally the same but vary in strength.

Construction—Vulnerabilities—Upgrades

Associated chapters in this handbook discuss building components and include a wide spectrum of optional enhancements. Chapter 15: "Penetration Rates and Data Base" provides a listing of building components and their penetration times. This may be considered a catalog of items for upgrading the modification and/or new design of a facility. These may not be directly related to an igloo or other facility, but it is sincerely hoped that they may be a stimulus for adaptation or development of unique and effective deterrents.

The following itemized construction features are components associated with igloos. The vulnerabilities of each are indicated as are options for incremental enhancements.

Locks

Existing — Existing igloos are usually secured with one or two padlocks attached to a staple which is run through a hinge fabricated from mild steel. Latches on each door leaf activate head and foot bolts that hold the door closed, but the latches do not have locking provisions (Figure 9-8).

Penetration —

b3

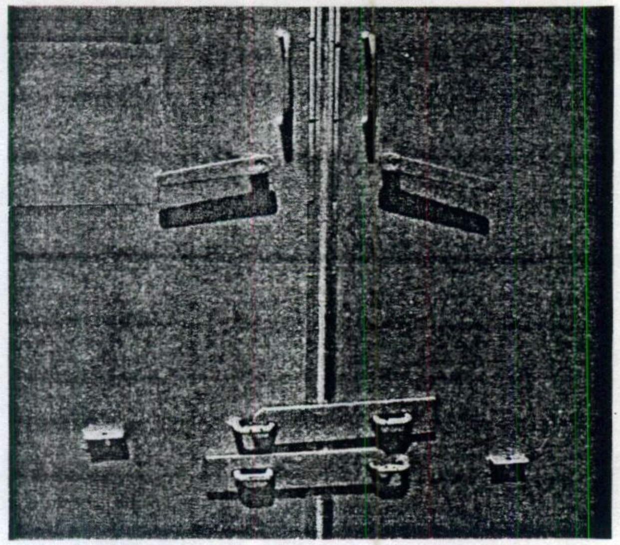


Figure 9-8. Door Locks for Conventional Igloos

b3

Enhancement — A first incremental improvement to a fully exposed padlock is to install a shroud over the entire lock, leaving only the bottom open for operation of key and lock (Figure 9-9).

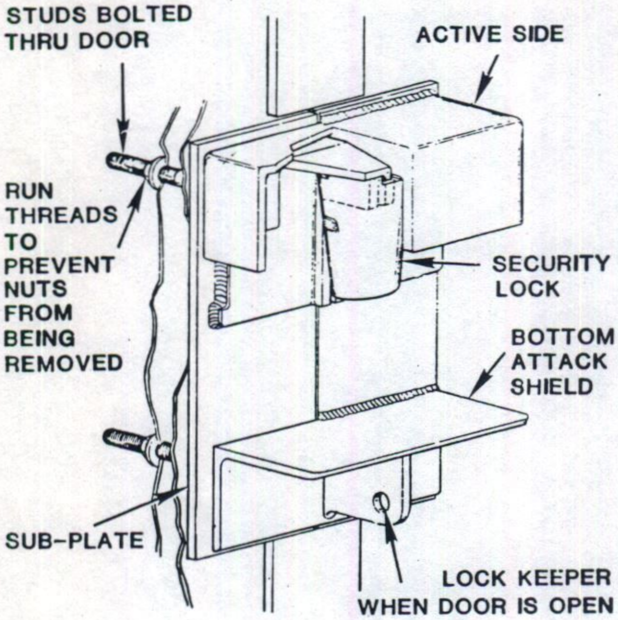
b3

b3

The most effective door lock devised thus far is probably the "King Tut" block concept (Figure 9-11). This is a reinforced concrete block covering the lower portion of the door and placed over a steel beam inset in the base of the block and behind two posts.[2] A forklift is required to place and remove the block; this takes several minutes. The forklift is removed from the site during nonoperational periods.

b3

The concept of multiple locks, doors, and barriers will be discussed with subsequent topics.



HIGH SECURITY HASP HINGED RIGHT HAND MK 2 MOD 7 REF:(NAPEC DWG. 0955) WITH SUB PLATE AND STUD FOR CONDITIONS WHERE HASP CAN NOT BE WELDED TO DOOR FACE.

Figure 9-9. Shrouded High-Security Padlock[1]

Doors and Accessories

Existing — Penetration times and enhancements for igloo doors are discussed in Chapter 6: "Doors." Igloos normally have a pair of steel swing-doors. Each door leaf is approximately 5 feet wide, from 8 to 10 feet high, and 3 inches thick. These doors are attached by 3 or 4 strap hinges welded to the door and bolted into the frame. Some igloos have a slot at each door sill to permit the swing-door to be lowered down into it by means of special door jacks which may be removed. Simultaneously with the lowering of each door leaf, a heavy metal hook attached to the top of the door engages into a slot bracket which is an integral part of the door frame.

Penetration —

b3

Enhancement — The door hinges may be protected by welding a Z-bar to the door which interlocks over the door stops, forcing the adversary to another attack method. b3

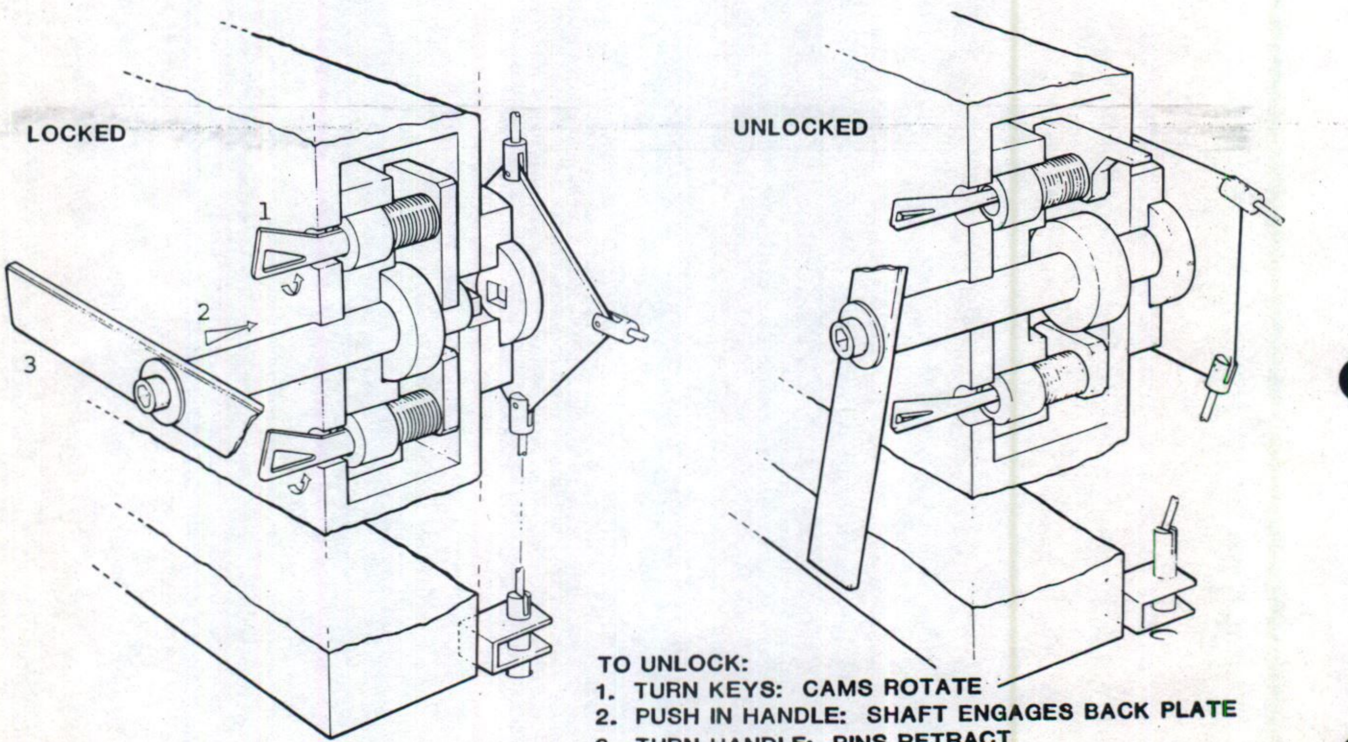


Figure 9-10. Double Security Cam Lock

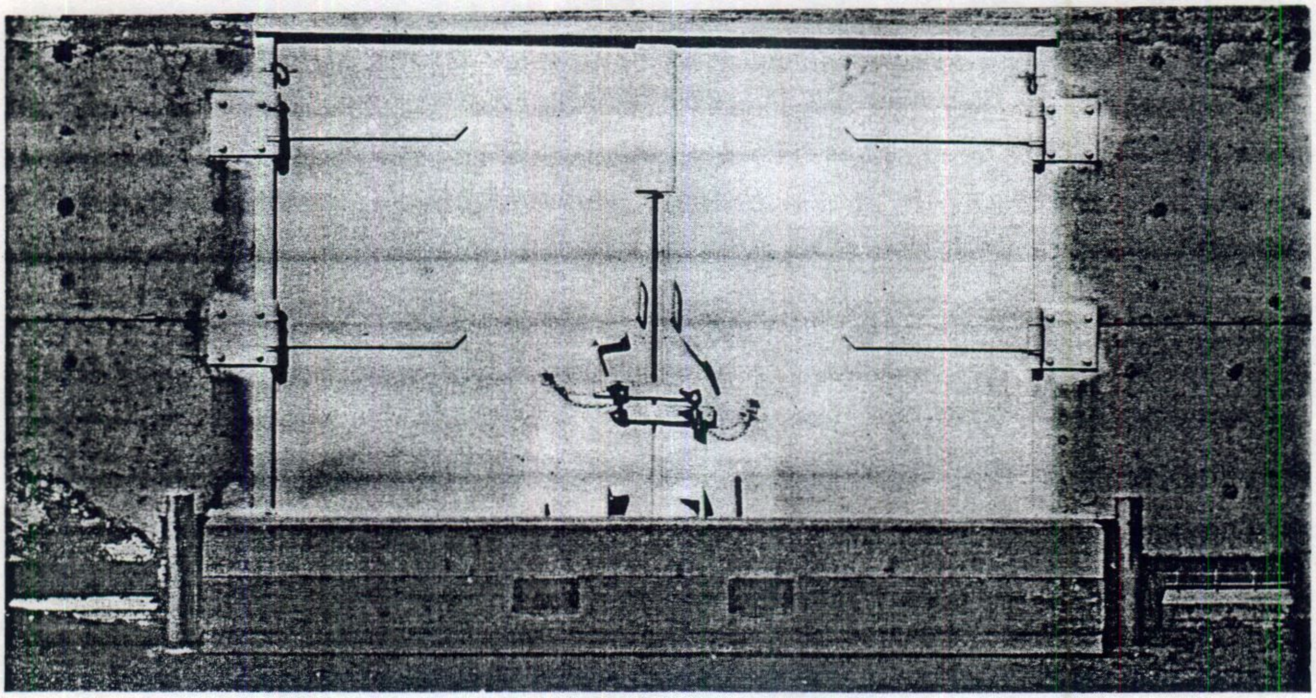


Figure 9-11. One Version of "King Tut" Door Block

b3

The "King Tut" block concept may be applied to door enhancement by using a large reinforced concrete block completely covering the entire doorway. This block could be equipped with air pressure bearings and the block installed on a smooth concrete slab to move the block easily but restrict its movement when source of air is removed from the site during nonoperative times. Also, the air couplings may be of unique design and/or locked within a recess of the block.

Exposed Concrete Wall

Existing — The front wall of the igloo encloses one end of the building as well as being a retaining wall for the overburden. The entrance wall is typically 12-inch-thick reinforced concrete, and the adjacent wing walls consist of varying additional reinforcing and thickness.

Penetration — b3

Enhancement — These walls may be enhanced by installing an additional wall section in front of the existing one by a technique called "tilt-up" construction.[3] This is an established method generally employed for new construction where the wall is poured flat on grade and tilted up into place on a new foundation. Costs are greatly reduced over the conventional method of pouring concrete in place. The thickness of the wall may vary with the increased delay time required. Figure 9-12 illustrates a tilt-up wall addition to a sectional, foreshortened, igloo model which also includes a second door and frame.

Installing a tunnel slightly larger than the door and extending 15 to 20 feet reduces the exposed igloo wall face area to attack. This permits the use of earth overburden adjacent to the wall in sufficient quantities to establish an effective barrier as well as allow impediments to be placed within the restrictive entrance. Figure 9-13 illustrates this as well as other enhancements to be described later.

Arched Roof-Wall

Existing — The arched section of the igloo transmits the dead load of the structure, the live load of the overburden, and any potential dynamic load of explosive charges to the continuous reinforced concrete footings. The foot-

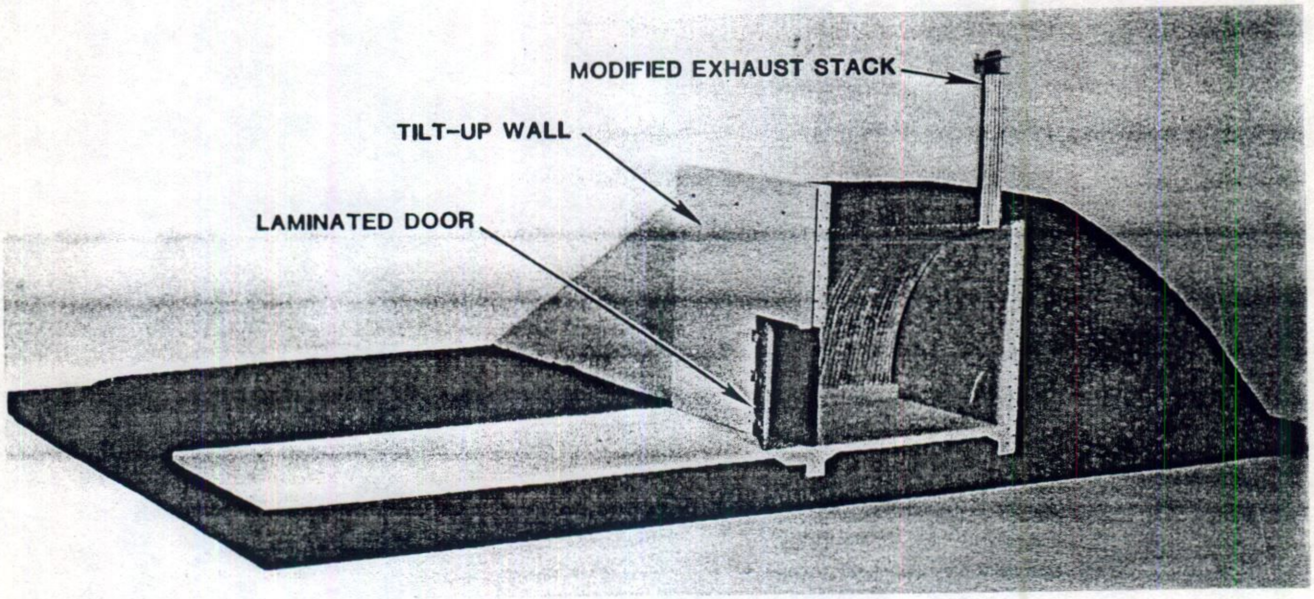


Figure 9-12. Tilt-Up Wall Addition — Igloo Model Sectioned and Foreshortened

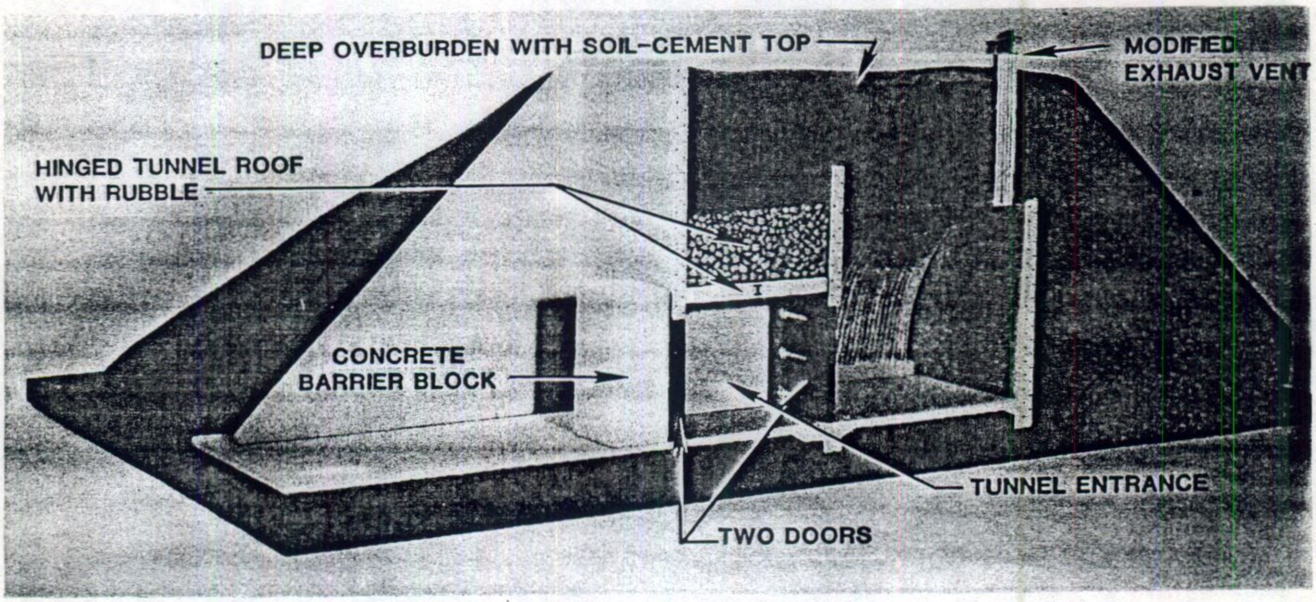


Figure 9-13. Foreshortened Igloo Model with Various Enhancements

ings are usually tied together in several places by modified tie beams to keep the footings from being forced apart by imposed loading. Footers vary in width, depending on soil-bearing capacity, construction type, and depth of overburden.

Most of the original military storage igloos were constructed of reinforced concrete arches until research and testing indicated that debris from the detonation within one igloo could penetrate an adjacent igloo. Since that time, military specifications have recommended that the arch be constructed of corrugated structural metal plates. The reinforced concrete arch usually varies uniformly from 6 inches at the crown to 12 inches at the base, and the steel plate arch is normally 1-gauge (coated thickness 0.280 inches) steel.

Design recommendations for earth-covered steel arch magazines provided in the joint publication by the Departments of Army, Navy, and Air Force, *Structures to Resist the Effects of Accidental Explosions*, state: "In general, it can be said that the steel thickness is roughly that required to support approximately 25 feet of earth fill and the steel thickness increases with the span of the arch."[4] Table 9-2 indicates the steel thicknesses specified for various magazine widths. Most explosive-storage igloos are constructed in accordance with Corps of Engineers standard drawings and specifications, which adhere to these arch recommendations.

TABLE 9-2

Required Steel Thicknesses for Various Magazine Widths

Width of Magazine (feet)	Steel Thicknesses Required	
	Gauge No.	Inches
14 or less	8	0.1644
16	7	0.1838
18	5	0.2145
20	5	0.2145
22	3	0.2451
24	3	0.2451
26	1	0.2758
28	—	0.375
30	—	0.375

Penetration —

b3

Enhancement — The modification of a wall-roof section for additional penetration resistance is costly and difficult to accomplish. The most effective method for protection is to install a deep overburden on top of this section and force the adversary to remove it. This will be discussed in the following building section, "Overburden."

Overburden

Existing — Specifications for igloo overburden construction usually call for a minimum of 2 feet of earth cover at the rear, sloping upward to approximately 3 feet at the front. This provides drainage away from the entrance. Erosion of the soil presents a continual maintenance problem in areas of large amounts of precipitation and even in arid regions over prolonged periods of time. Erosion degrades the resistance of the soil against penetration by reducing the amount of soil that must be removed. Moisture produces a bulking effect in the soil which, in turn, loosens it and permits easier soil removal.

Penetration —

b3

Enhancement The deeper that earth overburden is installed over an igloo, the more time will be required for its removal, regardless of method used—manually, mechanically, or explosively.

Sandia National Laboratories (SNL) constructed a full-scale multiplate arch igloo in accordance with U.S. Corps of Engineers design and specifications. This structure was completed without the conventional earth cover (Figure 9-14) as a test bed for a controlled installation of a compacted earth fill to the maximum height possible without any additional structural modifications. A height of 10.5 feet above the crown of the arch at the traverse section centerline was completed (Figure 9-15). Strain

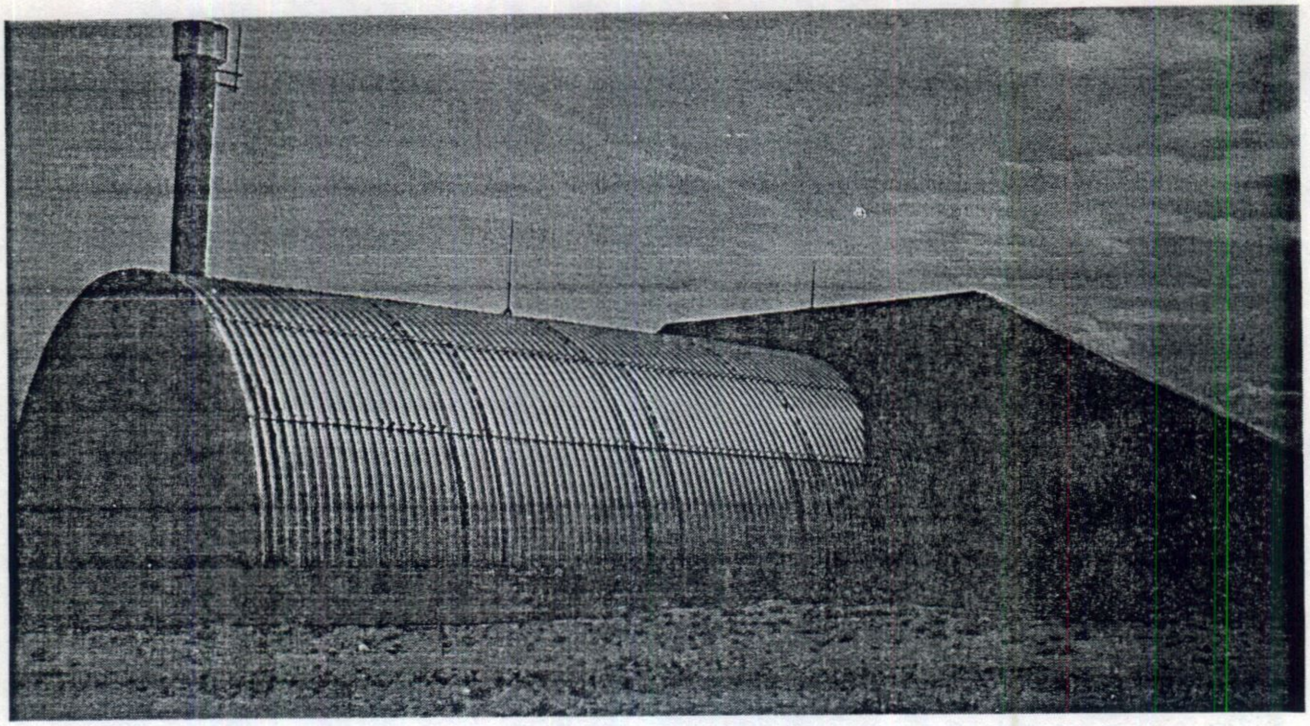


Figure 9-14. Conventional Storage Igloo without Overburden

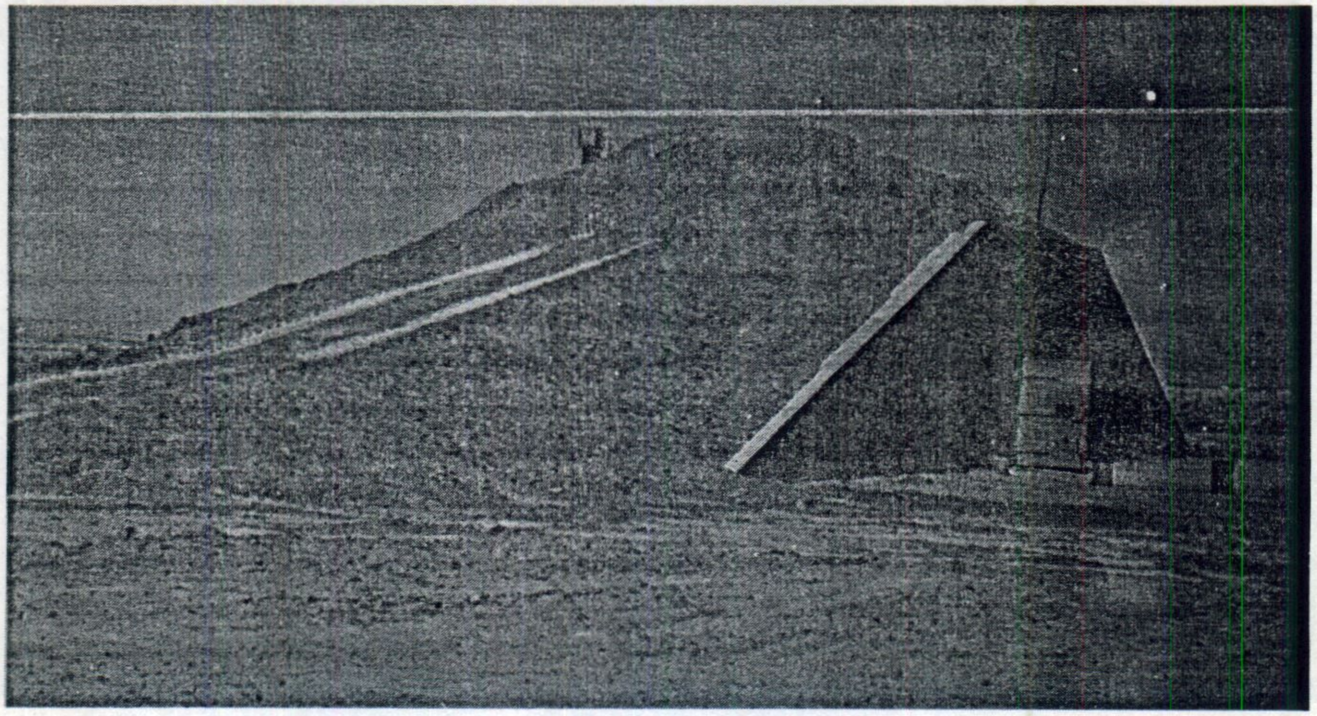


Figure 9-15. Conventional Storage Igloo with 10.5 Feet of Overburden

gauges were installed to measure the corrugated metal arch deflection as well as to make a series of survey measurements of the floor slab and footings during the overburden installation (Figure 9-16). The test results very closely approximated the analytical results of the flexible metal arch with the deviations attributed to bolt slippage and temperature effect before the arch was covered. Information published by Armco Steel Corporation[5] describes a recent application of the yielding ring theory, which provides a controlled-yielding joint connection for adjacent lapped plates, called keyhole slot connections. This load-relieving method means that the metal thickness of a structure may be reduced, or higher fills can be built over a structure. The assumed bolt slippage in the SNL igloo test may be based on the yielding ring theory, which would indicate that the load on the arch was relieved to permit the soil to carry much of the load instead of the structure.

Chapter 10: "Earth Cover and Overburden" addresses deep overburden excavation and added enhancements buried within the overburden and soil-cement or concrete cover for the overburden.

Utility Ports

Existing — The exhaust stack is located close to the rear of the igloo at the crown, with the induced air coming from louvered grills at ground level on each side of the front door and/or in the door. The size of the air vent openings is dependent upon the volume of the igloo; usually an exhaust stack varies from 12 to 24 inches in diameter and the intake vents are of comparable area. Most intake vents are protected by bar grillage set in the concrete wall and are usually smaller than a man-sized opening. The exhaust stack is usually equipped with either a ¼-inch-thick perforated steel plate welded over the duct at the crown of the arch or with ¼- to ½-inch-diameter steel rods spaced over the opening and set into the concrete of the roof arch.

Penetration —

b3

Enhancement — An exhaust stack large enough to afford entry could be enhanced by installation of a number of

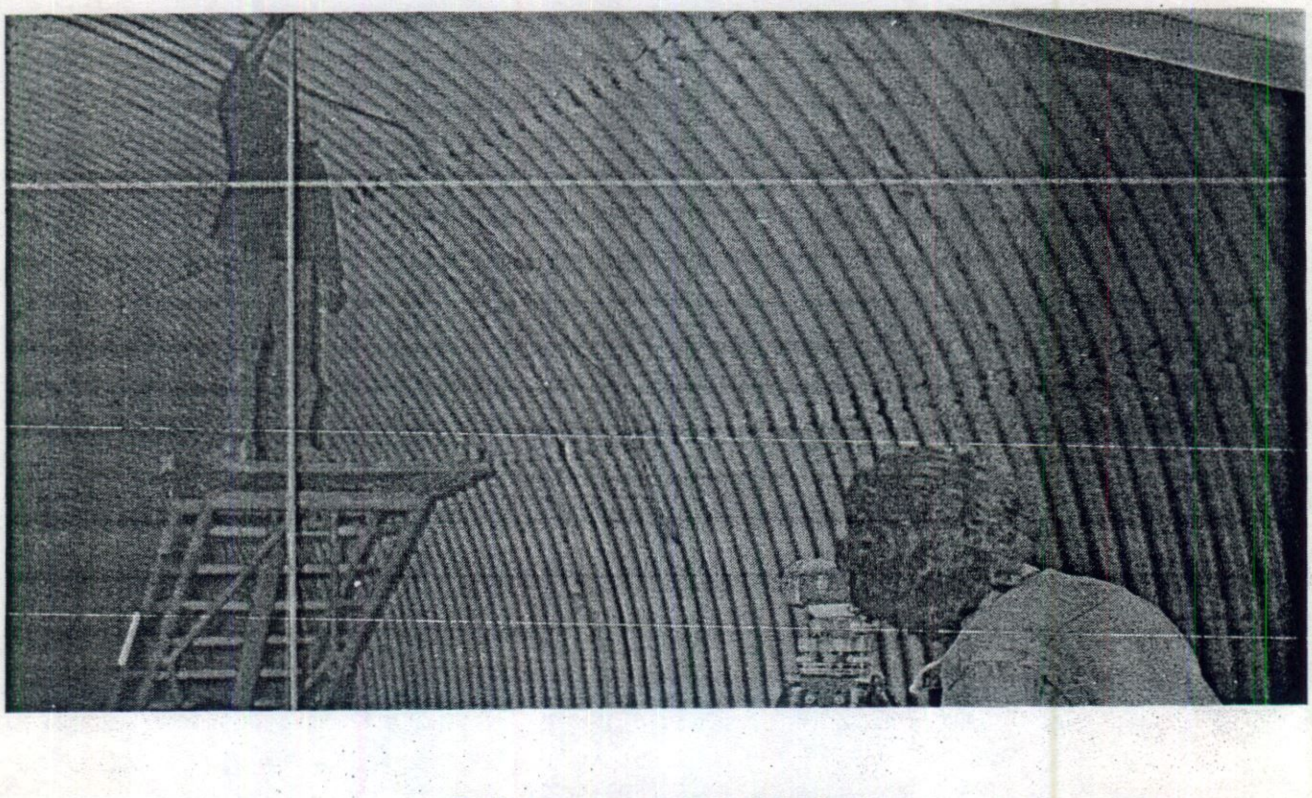


Figure 9-16. Survey of Igloo Deflections

small diameter pipes welded together and to the inside of the stack. Other possibilities would be to have a series of bends (in those that do not already incorporate them in their design) with turning vanes in the stack, or to relocate the stack to the rear wall, near the crown of the arch, feeding into a plenum chamber with smaller outlet vents.

The necessity of a ventilation system within the igloo should be investigated. It has been found that, in some instances, one was not required, and the openings were sealed. A small portable air conditioning unit may suffice for minimal requirements of humidification, cooling, filtering, or simple circulation.

Summary

In this type of structure, as in all security-oriented buildings, the goal should be a balanced structural design to uniformly increase the resistance to penetration. Individual components of a building may be further investigated and their enhancements extrapolated from associated chapters in this handbook.

A foreshortened, sectioned, igloo model (Figure 9-13) illustrates some of the enhancements which may be incorporated into an existing igloo:

- Concrete barrier block on air bearings at the main entrance. This may be duplicated within the tunnel at the second door.

- Restrictive tunnel entrance to the main structure with an additional, laminated door. The tunnel may have a hinged-roof concept which could be command- or intruder-activated to permit loose rubble to cascade into the entranceway.

- The exhaust vent as shown has many small pipes to restrict the opening size. This vent may have a series of bends or an offset at the rear of the igloo.

- Added overburden may be installed with a variety of obstacles for added enhancement. This may be topped with a layer of soil-cement or concrete.

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3. Joseph J. Waddell, "Tilt-up Concrete Walls," *Construction Specifier*, 29(10): 27-37 (Oct. 1976).

4. *Structures to Resist The Effects of Accidental Explosions*, Joint Publication by Departments of Army, Navy, and Air Force, TM5-13000/NAVFAC P-397 AFM 88-22, Supt. of Documents, Change #1, March 1971.

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CHAPTER 10

EARTH COVER AND OVERBURDEN

INTRODUCTION

In this chapter, earth overburden is discussed as a construction material to provide an effective barrier and deterrent against an adversary's attempt to gain entry to the underlying structure.

The prime consideration of most architects and engineers is to design buildings attractively and functionally as shelters for living and working. Design criteria seldom incorporate penetration specifications, with the possible exception of banks and similar institutions. Chapter 9: "Vaults and Igloos" considers the required component parts of a specialized building with better than average structural resistance to penetration, and from this it may be concluded that most contemporary buildings do not provide much penetration delay. Therefore, additional building hardening may be required to increase the delay for an adversary.

Overburden has been utilized by military engineers for many years as an economical and effective way to protect storage igloos (magazines) which house explosives from explosions in adjacent structures.[1]

ADVANTAGES

Penetration Resistance

A well-compacted, deep, earth overburden (in excess of 10 feet) will provide an effective time-consuming barrier against penetration. b3

b3

An adversary who is knowledgeable about the depth and nature of the earth overburden and its enhancements would be directed to a more vulnerable point of entry or be resolved to engage the response force. An insider could render little or no assistance to cohorts choosing to attack a facility through a deep overburden barrier.

Economy

Soil is nature's most abundant building material. It has the added advantage that no processing is necessary to immediately incorporate it as a protective material. This fact may be illustrated by a breakdown of the costs associated with the installation of an earth cover. Assuming the barrow pit is within a 2-mile radius of the construction site, the cost to convey the earth from the pit to the site, spread the material with a bulldozer, and compact the fill would be approximately $5.80/yd^3 (estimate as of the third quarter, FY79). This cost is significantly more economical than that of any other comparable protective material, such as concrete, masonry, or metal, even though more earth cover may be required for equal penetration delay.

An economic spin-off may be gained. "For energy savings it pays to build below ground."[2]

Design

New construction may be readily designed to accomodate the additional load of earth overburden to any desired depth with a relatively lower cost than is required to incorporate smaller quantities of more expensive materials. The modification of existing structures may present some problems, but this will be true for any additional superimposed building materials. Arched or domed structures are more adaptable since their inherent structural design allows the imposed loads to work laterally against the backfill. A fully-buried, arched structure may take full advantage of the arching effect of the soil, and much of the weight of the overburden will be dissipated into the adjoining earth.[3]

PENETRATION

Penetration rates for an earth overburden are dependent upon the physical characteristics of the soil and the depth necessary to gain access to the underlying structure. The physical characteristics of soil are type (structure), texture (size of soil particles), density (porosity of both dry and wet soil), and cohesiveness (shear strength as an adjunct of friction). These natural characteristics may be adjusted to produce optimum resistance to penetration by mixing soil types and textures which provide the best cohesive characteristics and compaction and hence produce the maximum density. If the toughest and heaviest soil is utilized as an overburden, the variable of depth will then be sufficient to produce the amount of delay time required for a particular set of conditions.

Excavation rates for several soil types and depths are shown in Table 10-1. These rates are for soils showing typical characteristics and having minor rock and clay content less than 35 percent.

Table 10-1 indicates that time is increased as the depth of excavation increases. This is true not only for machine excavations, but particularly for manual excavations. Soil types have various angles of repose; those having the smaller angles require digging wider holes to keep the soil from slipping back into penetration area of the excavation. All machines are limited as to the depth at which they can operate. These factors work in favor of having deep overburdens for more effective barriers.

Manual Tools

Penetration tests were conducted at Sandia National Laboratories by a team of four men digging and resting in pairs on a man-made mound of earth which simulated the overburden of a storage igloo.[5] This mound was approximately 6 years old so that normal settling, compaction, and weathering had had ample time to occur. Figure 10-1 represents a composite of two digging tests with an average of 26½ minutes required to dig a 36-inch-deep hole.

TABLE 10-1[4]

Excavation Rates

	Manual		Mechanical*	
Type Soil**	Depth 1 to 2½ ft (yd^3/h)	Depth 3 to 5 ft (yd^3/h)	Case 580 0.0819-yd^3 Bucket (yd^3/h)	Cat 225 7/16-yd^3 Bucket (yd^3/h)
1	2.0	1.4	7.37	83
2	1.4	1.1	7.67	72
3	1.1	0.9	8.16	86
4	0.9	0.7	6.86	60

*Average rate for 12-foot-deep excavation. There are many manufacturers of excavation equipment as well as many types of equipment, such as backhoes, front-end loaders, and combinations of these. The two machines listed have digging rates for four different-capacity buckets.

**Type 1—Sandy Gravel, Type 2—Sandy Topsoil, Type 3—Sandy Loam, Type 4—Sandy Clay

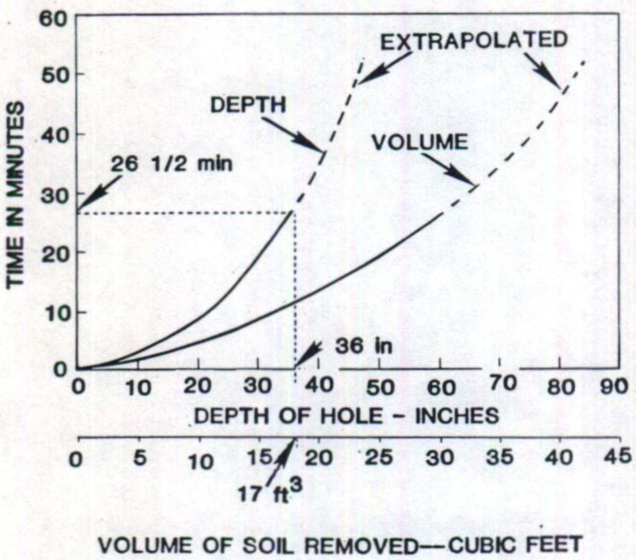


Figure 10-1. Overburden Penetration—Hand Tools

Figure 10-2. Unenhanced Sand Dig Test

The University of New Mexico Civil Engineering Research Facility made a soil investigation report on this mound which revealed the soil to be extremely tough and highly penetration-resistant.

A soil penetration test was performed as part of an igloo penetration attack at Crane Naval Ammunition Depot, Indiana.[6] The attack team was comprised of four men shoveling a moist, grassy fill. It required a little more than 4 minutes to clear an area approximately 1½ feet in diameter on the igloo crown to a depth of 31 to 36 inches. The easy and rapid penetration of this soil was due to the uncompressed, bulky soil condition.

A sand penetration test was conducted at Sandia National Laboratories through a 4-foot-deep, loose, dry, sand overburden by a group of five men working as a team. A total of 10 minutes was required for the attack team to disembark from its truck, dig the hole, place a dummy explosive charge, and retreat approximately 250 feet from the site. Hand tools were used exclusively on this test: a variety of different-size shovels and buckets. The excavation was approximately 6 feet square at the top by 40 inches square at the bottom (Figure 10-2). A subsequent sand penetration test was made on the same 4-foot-thick test section, but in this test the overburden was enhanced by seven layers of chain-link fence fabric laid horizontally at 6-inch intervals. A total of 25 minutes was required from the start of the test to dig the hole, place a dummy explosive charge, and retreat from the site. The first layer of fabric was cut with a power demolition saw, but the saw stalled in the sand on the successive layers of fabric and hand-operated boltcutters were substituted (Figure 10-3). This hole was smaller than that in the first test due to the restraining of the sand by the fabric, and the size of this hole permitted a steeper excavation (5 feet 2 inches by 5 feet 8 inches at the top and 1 foot 5 inches by 2 feet 0 inch at the bottom) (Figure 10-4).

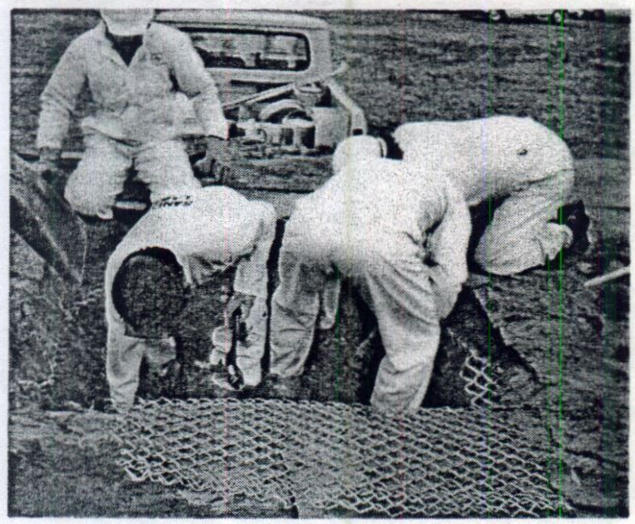


Figure 10-3. Third Layer of Fabric Mesh. Hand boltcutters is most effective tool.

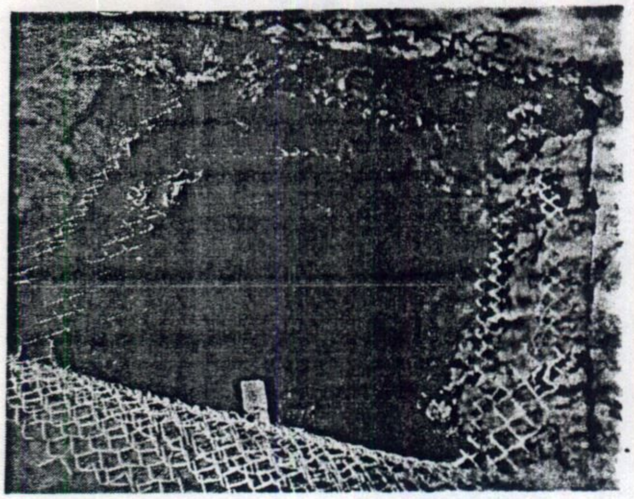


Figure 10-4. Test completed. Dummy explosive charge placed. Note taper of hole with reinforcing.

Heavy Equipment

An earth excavation test was conducted at Nevada Test Site (NTS) using a Warner & Swasey, Gradall (G-1000) Hydraulic Excavator (backhoe) with a telescoping arm equipped with a 48-inch bucket (about 1 yd^3 capacity) (Figure 10-5). A hole 15 feet deep adjacent to a reinforced concrete wall was dug, removing 135 cubic yards of earth in 61 minutes. This rate may be considered the minimum time possible for this machine and soil type (sandy clay with interspersed rock about 1 ft^3) since the operator was an exceptionally skilled journeyman. A second excavation test was performed using the same hole filled with boulders, varying in size from 1.5 yd^3 to 1 ft^3, randomly placed to insure interlocking filling of the voids (Figure 10-6). These were removed with the same machine and operator as in the foregoing earth excavation test. All rock impediment was removed from the excavation in 1 hour and 46 minutes. Additional delay time may

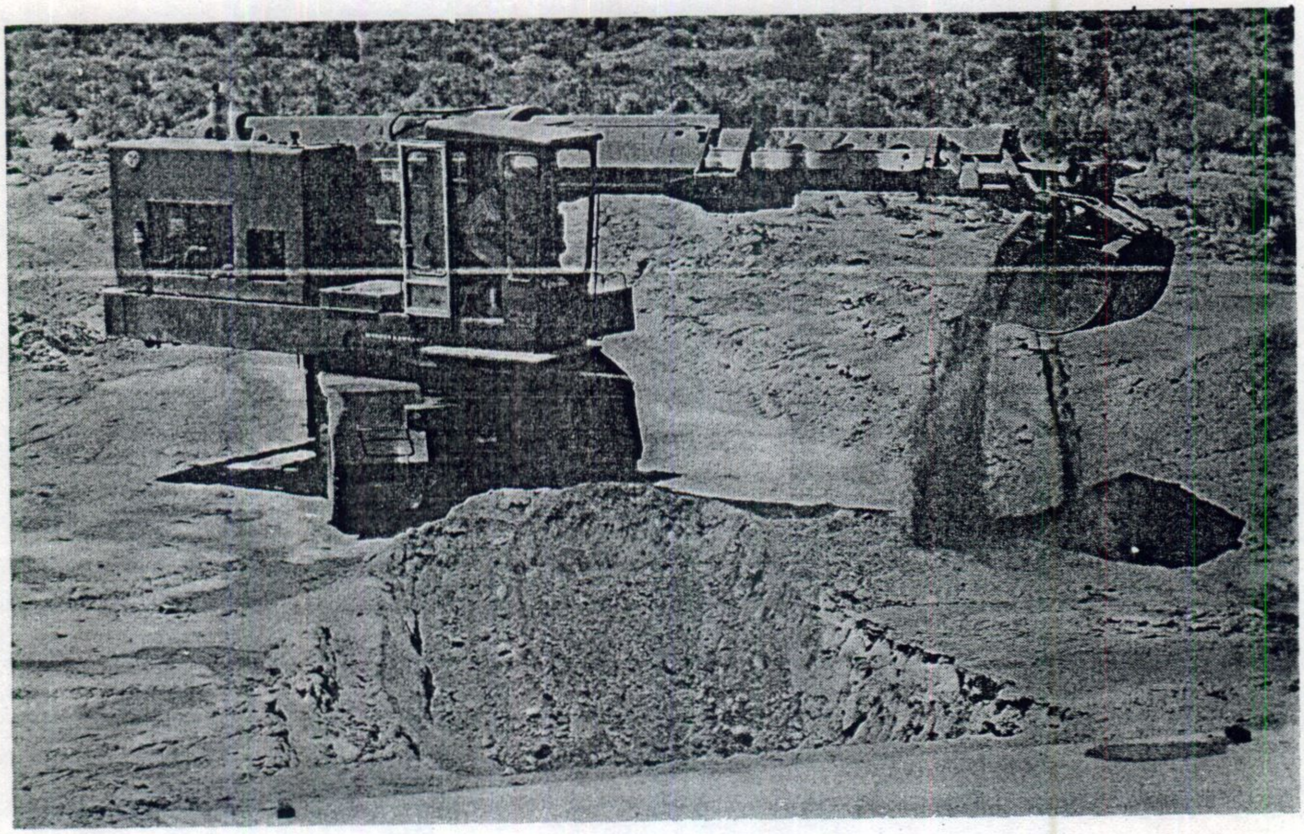


Figure 10-5. Earth Excavation Test at Nevada Test Site

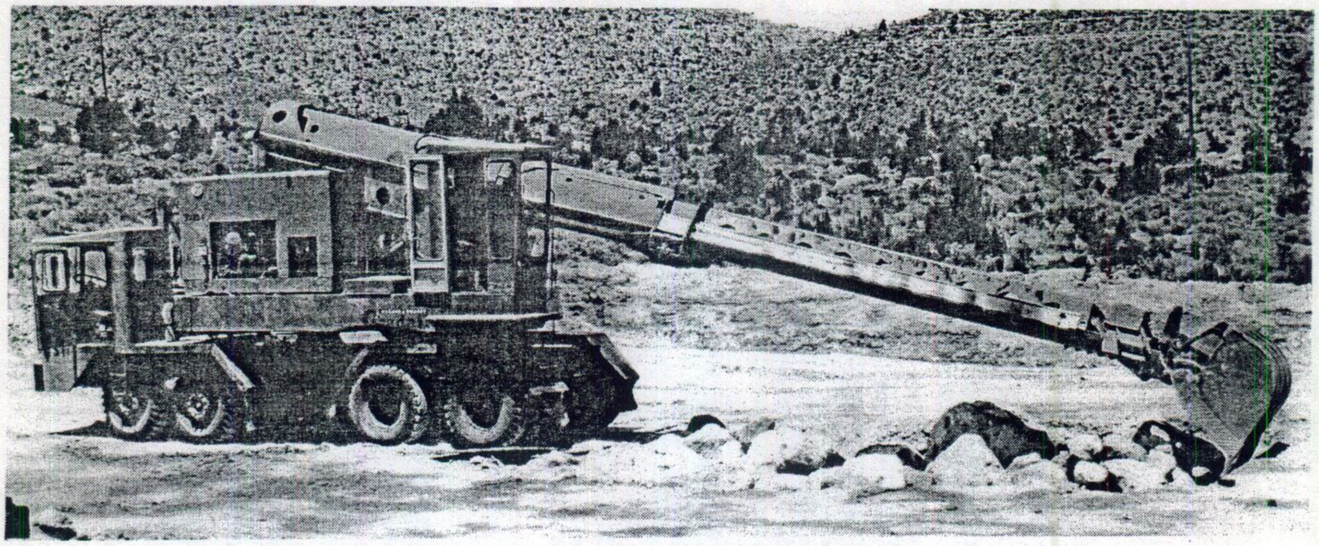


Figure 10-6. Rock Excavation Test at Nevada Test Site

have been gained by interspersing the rock layers with an earth fill vibrated and compacted to conceal the rock sizes and joints.

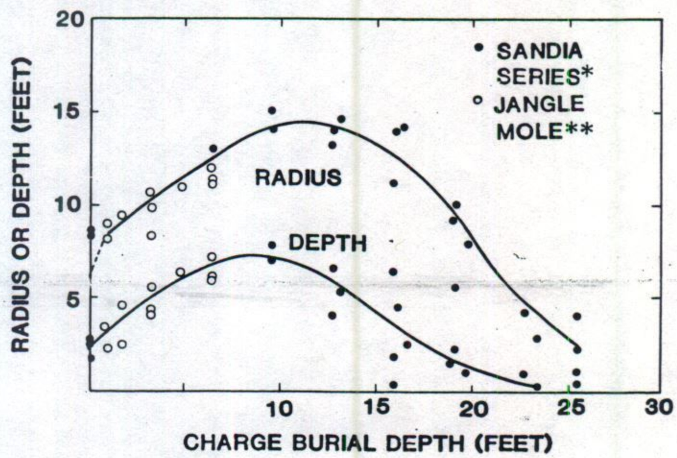
Explosives

Craters are the goal of the adversary using explosives as a tool for penetration. However, test results using explosives for excavation have shown that surface charges do not produce good crater results, nor do charges buried too deep since their gases are contained by the soil.

A series of explosive tests in alluvium soil* resulted in scaled data used to produce the depth-of-burst curves for crater radius and depth (Figure 10-7) for a single-charge weight. Project AIR VENT provides a later comprehensive depth-of-burst series in a single medium, i.e., the very homogeneous playa soil** of Frenchman Flats at NTS.[7] Due to the unusual uniformity of the medium, the results were especially consistent (Figure 10-8).

*Alluvium soil, usually coarser- grained silt and sand, deposited by a stream.

**Playa soil, usually fine, silty soil, is found in a flat-floored bottom of an undrained desert basin.



*B. F. Murphy, *High Explosive Crater Studies: Desert Alluvium*, SC-4614 (RR) (Albuquerque: Sandia Laboratories, May 1961).

**D. C. Scahs and L. M. Swift, *Small Explosion Tests, Project MOLE*, Vol. I and II, AFSWP-291 (Menlo Park, California: Stanford Research Institute, December 1955).

Figure 10-7. Crater Radius and Depth vs. Charge Depth-of-Burst for 256-Pound Charges in Alluvium

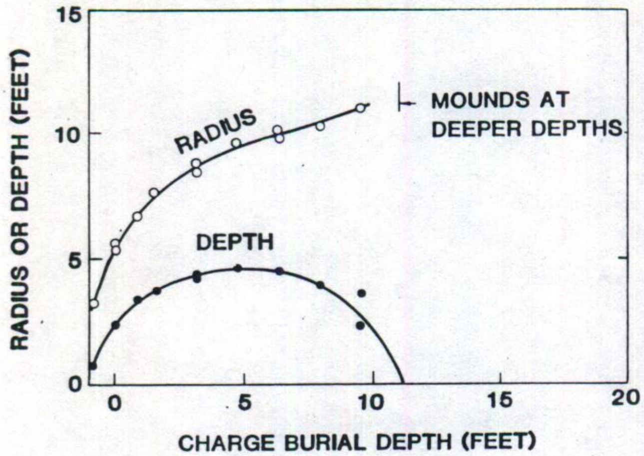


Figure 10-8. Crater Radius and Depth as a Function of Charge Depth-of-Burst for 256-Pound Charges in Playa

Test results have been compared with scaling techniques. To date, there has been no experimental refutation of $W^{1/3.4}$ scaling for buried charges.[7] (W = explosive charge weight.)* The hypothesized appearance of a crater created by 100 pounds of TNT explosives buried 10 feet deep (based on characteristics derived from information in Figure 10-7) is shown in Figure 10-9.

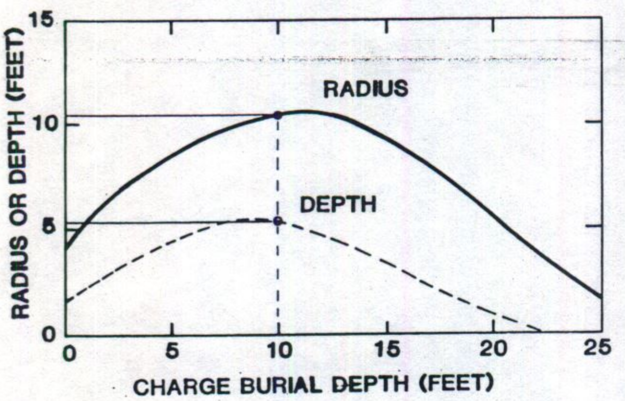


Figure 10-9. Crater Radius and Depth vs. Charge Depth-of-Burst for 100-Pound Charges in Alluvium

*Theoretically, the scaling law states that a given explosive pressure will occur at a distance from the explosion that is proportional to the cube of the energy yield.

When explosives are used as an attack tool against any barrier, the time necessary to bury the charge, ignite the fuse, retreat a safe distance from the site, and return must be accounted for in the series of events. The retreat distance is based upon the charge weight which produces overpressure and shrapnel. Explosives used against overburden produce a hole with rubblized debris at the bottom which requires additional time to dig out.

An explosive test was conducted at Sandia National Laboratories on a manmade mound of earth simulating the earth overburden over an igloo.[5] This is the same mound of earth as the manual excavation test site previously described. A hole 8 inches in diameter by 8.5 feet deep was made by using a mechanical drill. (This could have been expedited by using a 15-pound shaped, standoff explosive charge.) This hole was loaded with 100 pounds of blasting agent and detonated to create a crater 11.5 feet in radius by 4.5 feet deep. The crater was left with approximately 4 feet of loose fill rubble (Figure 10-10). A compilation of actual test times and those derived from rate tables in Chapter 15: "Rates and Data Base" indicated a total time required for the explosive and hand excavations to the surface to be penetrated (8.5 feet deep) would be approximately 22 minutes.

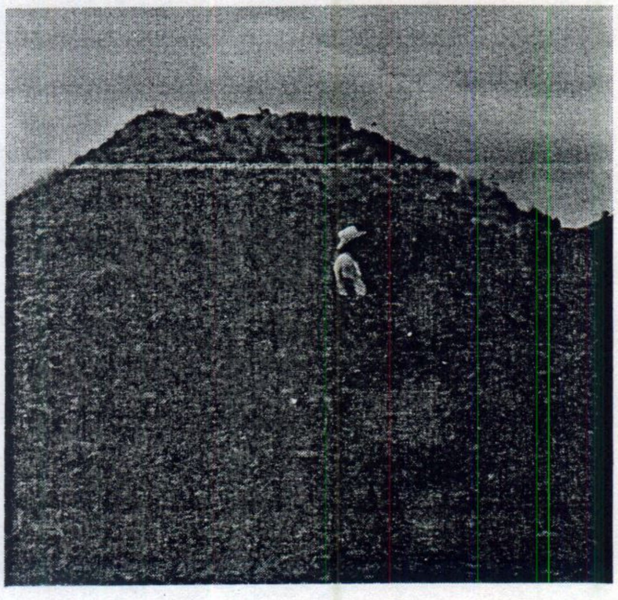


Figure 10-10. Crater Produced by 100-Pound Blasting Agent

An underground structure is not as vulnerable to significant damage as an aboveground structure subjected to an explosive detonation of equal magnitude and proximity of the charge. There are three zones an underground structure is subjected to by an underground detonation.[8] (See Figure 10-11.) The damage to an underground structure within the first zone, or the crater area, may be complete destruction. In the second zone, the earth has been ruptured and compressed by plastic deformation (approximately 2½ times the crater radius). The damage in the second zone is based upon the following factors: size, shape, flexibility, and orientation of the structure in respect to the blast and the soil characteristics. This damage may be slight to severe. The third zone is beyond the plastic zone; here the effects of ground shock are relatively unimportant and the damage may range from none to slight, depending upon the same factors listed for the second zone.

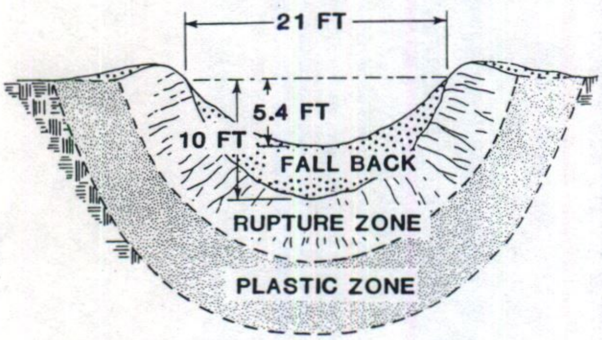


Figure 10-11. Typical Blast Effects for 100-Pound Charge with Depth-of-Burst at 10 Feet

Generally, underground arched or domed structures may withstand greater static and dynamic loads than box-type structures of equivalent cross section. The arching effect of soils, as referenced in Chapter 9: "Vaults and Igloos," is also significantly evidenced in transmitting part of the blast-induced pressures around underground structures rather than through them.

ENHANCEMENTS

The most effective enhancement of overburden for resistance to penetration that has been tested at Sandia National Laboratories to date is the use of soil cement.[9] This is a mixture of soil and cement with a relatively small moisture content as compared to concrete. A test section of soil cement (10 feet wide by 20 feet long by 2 feet thick) was constructed. One-half (100 square foot surface area) was unreinforced; the other half was reinforced with five layers of woven wire fabric (6 by 6 inches and 10 by 10 gauge).

Five tests, using hand tools, power tools and explosives, were conducted on this slab and are summarized in Table 10-2.

Soil cement is usually installed in the field by mixing with scarifiers and blade scrapers and then rolled. The shotcrete[10] method of applying Gunite may possibly be adapted to the installation of soil cement. This method could be used on inclined planes such as igloo overburdens where it is not feasible to use heavy rollers. Fly ash, which could be used in shotcreting, is being investigated for use in soil cement. This technique may increase penetration resistance and decrease costs.

Conceptual designs have been advocated for incorporating into the overburden a variety of complex composite assemblies rather than maintaining a homogeneous mass. Composites of ordinary construction or scrap materials can be incorporated into new or existing facilities to provide significant additional protection.[11] There are innumerable materials that can be utilized in the overburden, each having a different degree of hardness and configuration; this complexity will confound the attackers since it will necessitate different tools and modes of attack. Scrap vehicle-tire casings, reinforced concrete rubble, stone boulders, brick or masonry rubble, chain-link fence fabric, and crushed car bodies are some of the items to be considered. Any of these items interspersed in alternate layers with compacted earth and possibly topped with a soil cement will significantly improve penetration resistance.

CONCLUSIONS

Earth overburden is one of the most effective barrier options since extensive time is required to remove it in large quantities, especially when it has been enhanced by introducing impediments.

One of the most appealing aspects of overburden is the economy of the material. Large quantities of earth overburden may be more economical than smaller amounts of conventional barrier materials. A cost comparison may be made for the following thicknesses of material: 1 inch of steel at $8/ft², 10 inches of reinforced concrete at $8.30/ft², and 30 inches (2.5 feet) of soil at 25 /ft². This comparison of costs reflects an equivalence of missile penetration depths (identical impact load) but does *not* give a relationship of barrier penetration rates.

TABLE 10-2

Soil-Cement Penetration Test

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The construction of a new industrial complex which must be protected from an adversary should be seriously considered as a totally buried facility (Figure 10-12). The uniformly deep overburden with appropriate hardening of the portals (pedestrian and vehicular), would be a substantial barrier against all threats. The deeper these structures are buried, the greater the penetration resistance. Existing structures would likely require modifications (perhaps major) to allow the use of large quantities of overburden. However, the significant increase in penetration resistance achievable with overburden should not be overlooked as an upgrading option.

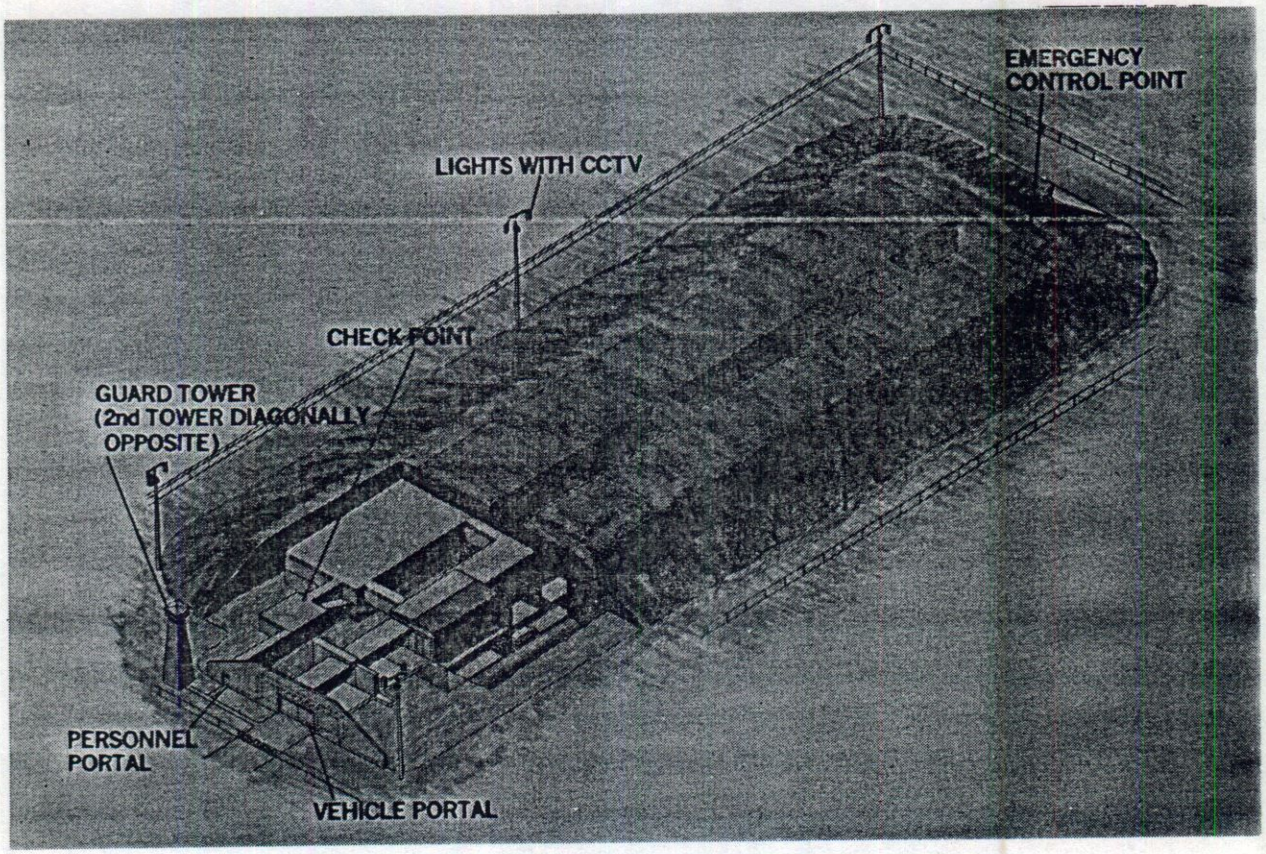

Figure 10-12. Operational Facility with Overburden (Artist Concept)

Initial penetration at the surface of the overburden may be discouraged by installing several feet of soil cement. Knowledgeable adversaries would be aware of the toughness and resiliency of this material. The advantages of erosion resistance and stability of moisture content are additional properties gained.

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Chapter 11

CHAPTER 11

AIRBORNE INTRUSION DETERRENTS (HELICOPTER)

INTRODUCTION

Airborne intrusion deterrents may be an important part of a physical protection system. The variety of options available to determined adversaries in the use of airborne modes of penetration presents special problems in providing significant delay times or effective deterrents. This chapter presents some of the material obtained to date from the study of such intrusions and some of the conceptual designs for barriers which may prevent or delay these intrusions. The primary threat treated in this chapter is the helicopter.

At present, indications are that there are few cost-effective barriers or deterrents to airborne intrusion in use at facilities other than those provided by the natural environment, e.g., power lines, poles, etc.

Helicopters and small fixed-wing and short-takeoff-and-landing (STOL) aircraft pose a very significant threat of intrusion by adversaries and/or their escape with material. Regardless of whether they have powered light capability, all types of airborne threats (including parachutes, hang gliders, etc.) can be considered intrusion threats when used in conjunction with other vehicles.

THREAT VEHICLES

Airborne threat vehicles are classified as powered, nonpowered, intrusion, and intrusion/escape. Each vehicle has features that may be either advantageous or disadvantageous to the adversary, and it is presumed that his selection will be the one that best satisfies his scenario, e.g., a fast escape vehicle such as a helicopter, rather than a spectacular, but slow, hot-air balloon. The use of some types of airborne threats can be partially dismissed, e.g., intrusion and escape by hot-air balloon, glider, or parachute.

Some aircraft will not be examined in detail; it is doubtful that jumbo jets, military fighters, or bombers could be used as intrusion vehicles. However, they must not be completely ruled out because they could be used to deploy a paramilitary group or to parachute adversaries into a facility. However, deterrents against helicopters, a more likely threat, are usually effective against the other types of aircraft.

The following are some attributes that airborne intrusion threats, powered and nonpowered, could possess:

- The ability to surprise, e.g., by parachuting men and equipment into a facility
- The ability to operate in inclement weather and, with special equipment, in darkness
- The ability to work in concert with surface adversaries and to serve as an escape vehicle
- The ability, in the case of a helicopter, to hover, making it possible to lower men and equipment inside a facility
- The possibility of being equipped with firepower and consequently used as a firing platform to defeat or delay a response force
- Easy availability through legal rental and leasing or through illicit procurement from the military, law enforcement agencies, company and emergency groups, or private sources; also, confusion with normal flight activity. (Normal and legal use of aircraft in the vicinity of a site by other groups may tend to lower alertness to the threat and cause hesitation in assessment of the true intentions of an adversary.)

Short-Takeoff-and-Landing(STOL) Aircraft

A STOL aircraft is a powered intrusion and escape vehicle for both men and material. This aircraft requires a landing space which has a minimum length of approximately 500 feet (152 metres). It can also be used to deliver parachute-dropped adversaries directly into a facility.

Conventional Fixed-Wing Aircraft

A conventional fixed-wing aircraft is a powered intrusion and escape vehicle which has a limited capability for delivering both personnel and material. Some fixed-wing aircraft models require a landing and takeoff area which is longer than the area the STOL aircraft requires.

Gliders

A glider is a nonpowered intrusion vehicle for men and material which requires a completely clear area for landing. Powered hang gliders could be used as either an intrusion or an escape vehicle at some facilities.

Exotic Vehicles

Although they are spectacular, exotic vehicles such as hot-air balloons and rocket packs have limited capacity and would probably not be used as intrusion vehicles. At this time, rocket-powered devices are mostly experimental and not readily available.

Vertical-Takeoff-and-Landing (VTOL) Aircraft

A vertical-takeoff-and-landing (VTOL) aircraft such as a helicopter would seem to be the most likely intrusion and escape vehicle. It does not require a prepared landing area, nor does it have to land at a site in order to deploy or pick up adversaries. Helicopters can be equipped for inclement weather and night operation and can be armed for assault. Depending upon the particular model (there are many types), helicopters may have single or tandem rotors, and may be powered with turbine, piston, or compound engines. The capacity of helicopters varies from 2 to 40 passengers or from 100 to 28,000 pounds (45 to 12,700 kg). Helicopter length beyond the radii of the turning rotors, varies from 28 to 100 feet (8.5 to 30 metres), and their height varies from 8 to 18 feet (2.4 to 5.5 metres). Helicopter speeds can reach 190 mi/h (300 km/h), and their range of operation can be 625 mi (1000 km).

HELICOPTER DETECTION

Often, when detecting a helicopter (by whatever means), there may not be enough alarm time—quite possibly less than 30 seconds—to assess intent. In some intrusion scenarios in which the adversary has carefully studied the terrain, facility layouts, obstructions, etc., the assessment time may be as low as 10 seconds.[1]

For most humans, a helicopter becomes audible at a distance of 1.9 miles (3 km) with an angular error of 9° to 18°, regardless of the helicopter's direction of approach.[2,3] Hearing the helicopter is unlikely at a distance of more than 2.5 miles (4 km). Furthermore, its noise can be masked by that of other vehicles, heavy equipment, trucks, tractors, or operational equipment such as large air-cooled air-conditioning condensers. Wind direction, terrain features, buildings, and vegetation can attenuate the noise and prevent its propagation.[4]

Visual detection may be hindered not only by terrain, vegetation, visibility (day, night, and climatic), flight altitudes, and buildings, but also by other elements such as normal flight activity in the vicinity. In addition, different kinds of aircraft are seen for different amounts of time, depending upon terrain,[5] and, because sight of the helicopter can be intermittently lost, its exact location is seldom certain.

Radar detection can be partially defeated by such flying techniques as "nap of the earth," in which the helicopter flies below the radar cone. At least one authority maintains that the helicopter, even when detected by radar, would appear to be an automobile.[1,6]

DETERRENTS

Deterrent systems and devices can be effective for more than one, but not necessarily all, airborne vehicles. For example, an arresting cable or safety barrier across a road may work against STOL fixed-wing aircraft but against a helicopter or a parachute. Deterrents may be active or passive as well as destructive or disabling to the vehicle and occupants.

Social and political environments may exist that hamper the use of some deterrents; however, for full effectiveness, lethal or semilethal deterrents should be considered in proportion to the assessed level of threat. This chapter makes no attempt to assess the threat or deterrent response level. It only suggests available deterrents to use as the threat level dictates. Some systems have been tested and proven effective, while others are less effective because they are easily defeated or require more development.

Short-Takeoff-and-Landing (STOL) Aircraft

Deterrents for STOL vehicles can be more passive than deterrents for helicopters. The STOL aircraft requires significant obstacle clearance and a runway which is clear of obstacles for a length of at least 500 feet (150 metres) and a width larger than its wing span. Many light aircraft have successfully landed and taken off from highways. To prevent this latter possibility from occurring inside a facility, the natural environment of obstacles such as fences and gates may prove effective. On roadways, barriers that reduce clear road length to less than 300 feet (90 metres) are effective. These barriers may consist of turns in the road, high structures to prevent safe landing, obstacles that can be raised, depressions, or movable barriers such as a highway median or vehicles.

Restricted Air Space

A restricted air corridor which extends upward to an unlimited altitude and whose penetration is punishable by law could be a deterrent; however, this would prevent only normal overflight. A detection system and a strong and alert response force would be required to apprehend or neutralize intruders. It would offer no physical barrier, only the possibility of detecting unlawful intrusion.

The threat of a strong response to illegal penetration of restricted air space may be a deterrent, but its effectiveness on determined adversaries is considered to be very low and hence may be more useful as an alarm and assessment component. Also, if the air space is too small, the allowable response time would be so short as to be useless.

Observation and Guard Towers

Observation and guard towers positioned in such a way that the guards have a complete view of a facility or sensitive area may have a dual function. They can be used as detection and assessment components or as a deterrent if hardened and armed. They may be equipped with audio and/or visual detection devices. Other features may include searchlights, high-intensity lights, or strobe lights. A tower may also be the control point for other deterrents such as dispensable chemicals or weapons.

Personnel located in a tower armed with a weapons system could be authorized and fully prepared to use it. The weapons should be loaded and mounted because intruder speed is a significant factor. Construction of the tower should be substantial and sufficient for occupancy in a hostile environment. Such a tower should be positioned to the advantage of the observation and guard force and should either be protected by reserve forces or else should not be located in a position where it could be easily isolated and its deterrent effectiveness negated.

Wires and Cables

Wires and cable nets are passive deterrents against helicopters. They can be suspended from towers, poles, or buildings. Existing power and communications transmission lines are a partial deterrent but are usually not sufficient because of height, spacing, etc. Their height above the surface can vary from 20 to 150 feet (6 to 45 metres), sometimes more; in western Europe, their height can reach 2000 feet (610 metres).[7]

The primary hazard to the helicopter from wires and cables is losing control of the craft after it hits the wire/cable system. The wires and cables may damage the rotary wings or the tail rotor, or they may become entangled in the controls. If loss of control were to occur while the helicopter is flying, landing, or hovering within the critical flight region, the results could be disastrous for the helicopter and its occupants. Damage to the rotary wings and controls could prevent autorotation to safety. Even if the helicopter were able to land, it probably would not be able to take off again. The dimensions of the cable and wire grid can be the controlling factor in how effective this deterrent is.

Support for the wires and cables can be steel towers, wood poles, buildings, or even trees. The size of the wire/cable strands can vary in diameter from very small, 0.01 inch (0.025 cm) to relatively large, 0.74 inch (1.88 cm). A small-diameter wire would damage a helicopter less than the larger diameter wire yet could still be effective. Larger cables with higher breaking strengths would cause more physical damage and be of more concern to pilots. See Figure 11-1.

Trees and Shrubs

Trees and shrubs comprise a passive deterrent system which is functional day or night. Its total effectiveness depends upon its density and the size of the area to be protected. Vegetation can be hazardous to helicopters and can be used to conceal surface deterrent systems. However, trees and shrubs used as deterrents to airborne intrusion can provide concealment for an adversary. On the other hand, they can also provide the response force with defensive positions.

The required canopy opening for a helicopter landing area is approximately 1.5 times its total length. To be effective, the canopy opening must be reduced to less than the overall length of the smallest anticipated helicopter, i.e., approximately 49 feet (15 metres).[8,9]

The thickness of tree trunks is a factor in their total effectiveness as a deterrent. If the helicopter rotors strike a tree of sufficient size, severe blade or transmission damage may occur, resulting in immediate forced landing or disaster. The minimum thickness of significant concern to a pilot is 10 to 12 inches (25 to 30 cm).[1]

Low shrubs, approximately 3 feet (1 metre) high and planted in irregular patterns on uneven terrain, may conceal other deterrents or prevent landing. When outside the diameter of the main rotor, the shrubs may adversely affect the slipstream and cause the pilot to lose control because of asymmetrical buffeting, resulting in a crash.[8]

Dispensable Deterrents

Dispensable deterrents in the form of obscurants, irritants, and incapacitants would be seemingly ineffective against helicopters; however, they can be effective against the crew. B. G. Cameron has shown that gases and particulates can be pulled into a helicopter while it is hovering at a height between 33 and 100 feet (10 and 30 metres).[10] Also, if incoming passengers have been exposed to irritants such as agents CR and CS, they may bring them aboard in their clothing. Dispensable deterrents are discussed in Chapter 13: "Dispensable Barriers and Deterrents."

Irritants could be dispensed in many ways, e.g., mine fields, rifle-launched grenades, and pressure systems. Some may be dispersed in combination with obscurants. Obscurants such as cold smoke and oil fog may be used but with little effect because the rotor wash would blow them away, and they may even conceal the intruders from response forces.

Incapacitating the Power Plant

Several suggested deterrents or disabling schemes aimed at incapacitating the helicopter's power plant appear worthy of consideration, but, at present, no practical way exists to apply them. For example, injecting large volumes of water, another noncompressible liquid, or even steel bolts into the turbine would destroy the blades and disable the vehicle. However, this might not be effective against twin engine models with transfer capabilities.

Another method of incapacitating the power plant could be to cause engine "flameout." Because most helicopters have turbine engines that require huge quantities of oxygen, removing the oxygen could cause "flameout." This removal can be done with intense heat,[10] fire-fighting materials such as CO_2, or other inert gases. The volume of gases, amount of heat, and time of oxygen deprivation have not yet been determined.

Steel Cable Nets

Steel cable nets can be used to encapsulate the helicopter or rotor blades after landing much in the same manner game and fish agencies trap animals or birds. The theory

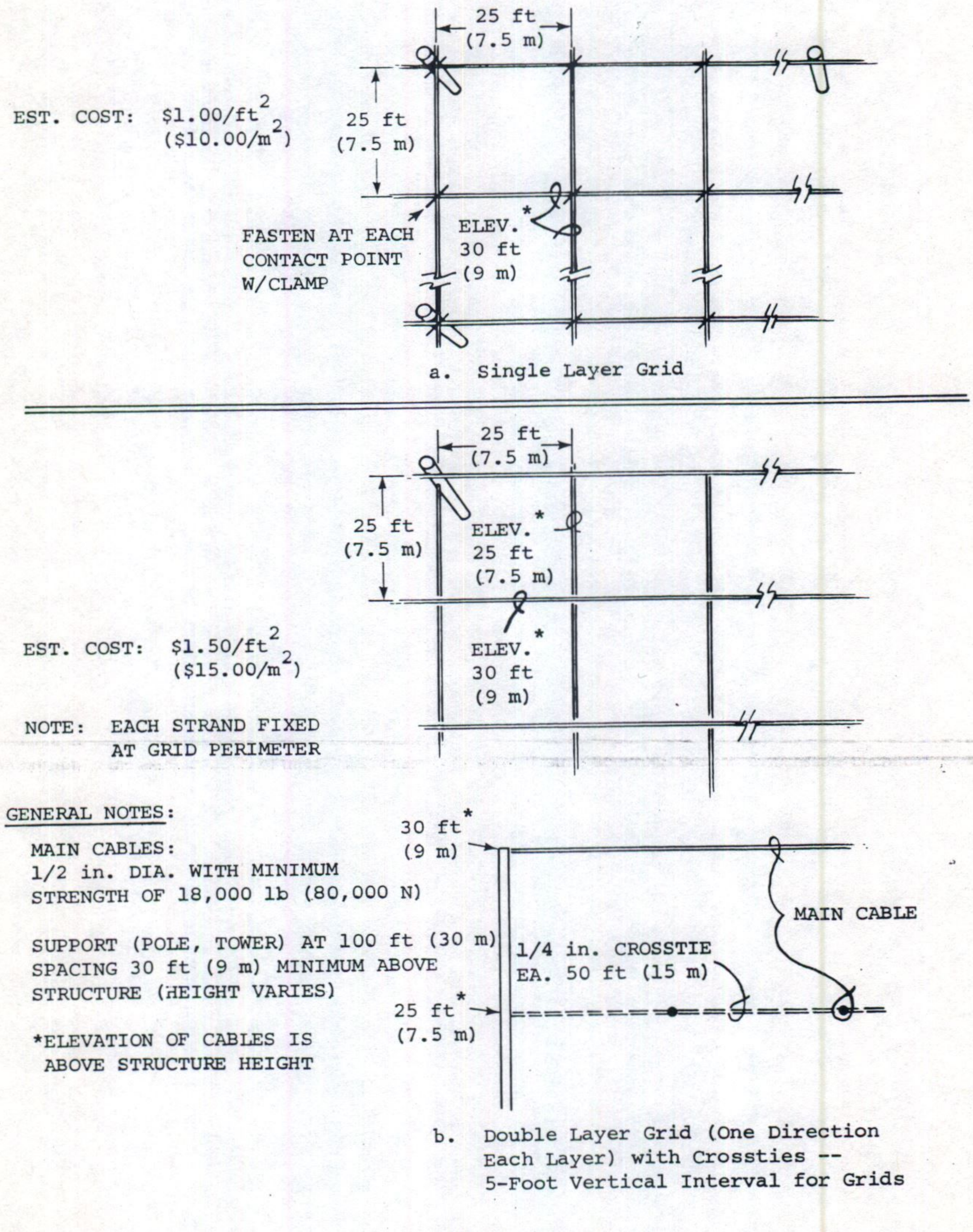
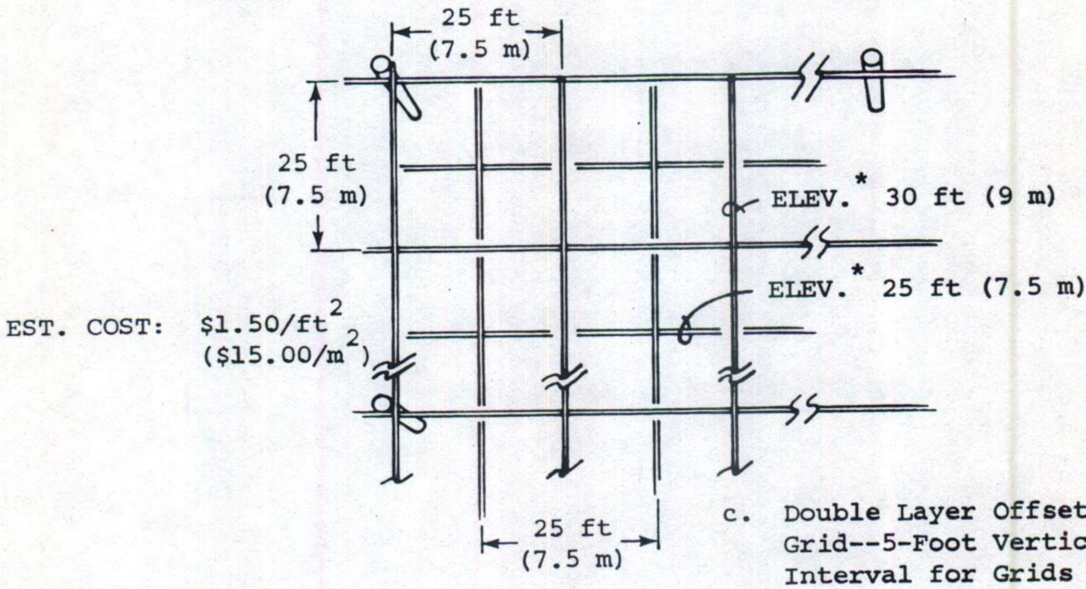
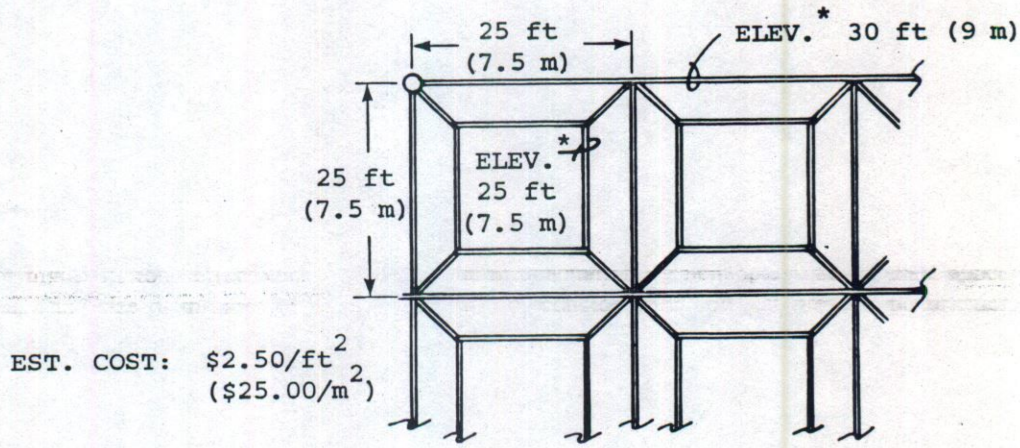


Figure 11-1. Antihelicopter Grids



c. Double Layer Offset Grid--5-Foot Vertical Interval for Grids

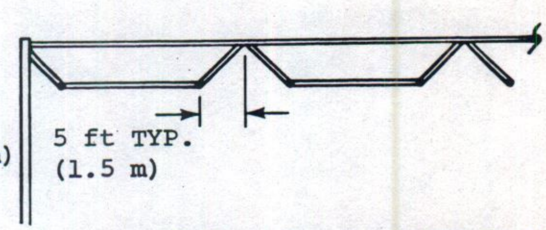


GENERAL NOTES:

MAIN CABLES:
1/2 in. DIA. WITH MINIMUM STRENGTH OF 18,000 lb (80,000 N)

SUPPORT (POLE, TOWER) AT 100 ft (30 m) SPACING 30 ft (9 m) MINIMUM ABOVE STRUCTURE (HEIGHT VARIES)

*ELEVATION OF CABLES IS ABOVE STRUCTURE HEIGHT



d. Double Layer Reducing Grid --5-Foot Vertical Interval for Grids

Figure 11-1. Antihelicopter Grids (Continued) is to force the crew to remove the net because it may damage the control systems and unbalance or destroy the rotors. Since the tail rotor is vital to stability and is weaker structurally than the rest of the helicopter, a net could destroy it. This deterrent could be deployed at fixed points in the sensitive area or mounted for mobility.

High-Intensity and Strobe Lights

High-intensity and strobe lights cause disorientation in some people, and can even cause some persons to have epileptic seizures. However, these lights have several weaknesses. They can be shot out or simply covered up by an adversary. In fact, their effectiveness is easily lessened if the helicopter pilot merely avoids looking directly at them. Of course, their effectiveness is greatly reduced if the adversary attack is launched during daylight hours.

During nondaylight hours, the normal lighting pattern of perimeter, street, and exterior building lights may illuminate a landing area for helicopters and actually may aid an adversary. Thus, turning off nonessential lights to eliminate this invitation acts as a deterrent. This, however, must not conflict with security criteria established for many sites where perimeter lighting and fire lights are required.

Weapons

The use of weapons may be a very effective deterrent. They can disable the helicopter in flight or on the ground and neutralize the occupants.

The vulnerability to projectiles differs for each helicopter element such as power plant, main rotor, flight controls, fuel system, flight crew, and hydraulic system. Some systems are redundant, and the loss of one will not immediately disable the craft. Usually, however, losing the main rotor blades or tail rotor can produce immediate and catastrophic results. Other factors to be considered are the flight mode of the helicopter (cruise in or out), speed, altitude, and hovering (most vulnerable), as well as detection range, climatic conditions, weapon deployment time, whether the weapons system is fixed or mobile, and the effective range of the weapons.

The type of weapon selected will be directly related to the helicopter being attacked and the amount of destruction desired. This choice could range from the 7.65-mm and 30-mm Gatling guns to infrared (IR), guided, and antiarmor missiles.

The vast choice of weapons available makes it difficult to recommend any without more detailed investigation and guidance from weapons experts. Furthermore, until the response force has the legal, social, and political authority for complete use, the effectiveness of weapons in disabling the helicopter or crew will be uncertain.

Underground Facilities

The concept of an underground or completely buried (overburden) facility with superhardened portals has significant merit (see Chapter 10: "Earth Cover and Overburden") as a deterrent to helicopters or to any airborne threat. The reason for this is that an underground facility, when employed in conjunction with the appropriate detection and response elements, tends to function irrespective of the method of transportation used by an adversary, i.e., foot, land vehicle, or any airborne means. The adversary must still contend with the hardened facility after arrival.

Loose Matter on Landing Area

When a helicopter is hovering or landing, the rotary wings push the air down and out, forming an air cushion. At the same time, part of the air is pulled around and upward and then pumped downward into the rotors from the top. During this time, there is a possibility that loose, light material on the landing surface may be pulled into the rotor blades or may strike the fuselage, causing extensive damage or injury.

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Chapter 12

CHAPTER 12

ARMOR

INTRODUCTION

Armor can be broadly defined as any material used to protect personnel, equipment, or structures from explosively propelled projectiles. Although armor is commonly thought of as heavy steel plate, many materials used in the construction industry, such as concrete, stone, wood, brick, or cinder block, provide appreciable resistance to projectile penetration. Gravel and sand have been used for many years as a convenient, effective, and economical means of defeating projectiles. The walls and doors of bunkers and igloos, which have been designed to preclude unauthorized entry, are often quite resistant to handgun projectiles. In many instances, minor modifications or the addition of complementary materials will greatly enhance the defensive characteristics of a structure.

The protection of personnel in gatehouses and guard posts may be an important element in the security of nuclear facilities. Hardening these structures against projectiles by the use of appropriate armor can enhance survival of the guards inside.

Armor is frequently categorized as heavy, medium, or lightweight. However, for the purposes of this handbook, armor is classified simply as either heavy or lightweight. Heavy armor is considered only briefly for the sake of completeness. Emphasis is placed on the uses of lightweight armor because of its wider application to fixed-site facilities and its adaptability. Lightweight armor is subdivided into opaque and transparent structural armor and body armor.

HEAVY ARMOR

Heavy armor generally refers to massive steel castings or plates, 1 to 8 inches thick, which are intended to resist penetration by modern missiles and artillery. Although commonly found in military combatant ships and tanks, steel of this thickness would seldom be used for fixed-site protection. If circumstances warranted a comparable level of penetration resistance, reinforced concrete, either alone or in combination with steel, would be less expensive than steel armor. The cost of concrete per square foot is approximately one-twentieth the cost of steel armor for equivalent protection levels.

Some general ballistic properties of commonly used construction materials are shown in Table 12-1. As Table 12-1 indicates, a fairly high level of protection can be obtained from 6-inch-thick concrete block walls.[1] The use of a few feet of overburden (see Chapter 10: "Earth Cover and Overburden") permits significant reduction in wall thickness without sacrifice of penetration resistance.

LIGHTWEIGHT ARMOR

Over the past decade, considerable work has been devoted to improving lightweight armor. Many of the improvements have been made possible because of advances in material technology; however, substantial credit must be given to M. L. Wilkins[2] and others[3,4] for developing a basic understanding of the mechanics of armor penetration.

TABLE 12-1

General Ballistic Properties of Various Construction Materials

Material Type	Density (lb/ft³)	Cost ($/lb)	.30-Cal M2AP[a] Penetration Depth
Wood, pine	30	.23	42
Sand, dry	100	.0041	14.5
Sand, wet	125	—	12.5
Soil, dry	90	.0015	14.25
Soil, wet	100	—	13.5
Cinder Block	120	.035	10.25
Gravel ⅜"	92	.0056	8.75
Gravel, 1" by 1½"	93	.0043	8
Gravel, 1½" by 2½"	96	.0053	6.5
Brick	120	.15	4.62
Concrete Block	150	.066	4.5

[a]Velocity 2765 to 2790 ft/s.

A number of sources exist from which information on the ballistic behavior of various lightweight armor materials can be obtained. A few of the more comprehensive collections of penetration data are listed in the bibliography. The AMMRC *Summary* by Mascianica[5] is a valuable aid in choosing protective lightweight armor materials for a variety of structures. However, most of the data cited is classified and, therefore, cannot appear in this handbook.

Two appendices have been included at the end of this chapter which are helpful in determining a weapon threat level and which provide a guideline for testing armor.

Appendix A: "Protection Class Level Criteria" provides classification data for various weapons. Appendix B: "Armor Specification" is a specification proposed as a standard for armor acceptance based on a Protection Ballistic Limit (PBL V_{50}).

Opaque Structural Armor

To determine the type of lightweight structural armor needed for a given facility, establishment of the required level of protection is the essential first step. It is helpful to group small arms into classes based on their penetrating capability or level of threat. The Protection Class Level Criteria (Appendix A) can be used for this purpose.

In choosing a protection level, two factors must be considered: (1) the worst-case, most probable threat and (2) the cost of armor to protect against this threat. It is important to remember that the cost escalates rapidly as the protection level increases. Frequently, because of cost considerations, a compromise in protection to a lower protection level must be made. Acceptance of a PBL V_{50} for armor, as opposed to the preclusion of penetration by a particular class of arms, reduces the cost. (For a definition of PBL V_{50}, see Appendix B, under "Protection Ballistic Limit (PBL V_{50}).")

Once a protection level is established, the next step is to determine the most economical method of achieving it. Regardless of whether a structure is old or new, installing a single layer of material which in itself provides all the needed protection is rarely a cost-effective solution. Rather, all the materials used in the structure or considered for use in new construction should be evaluated in terms of their function as armor so these materials can be combined in the most cost-effective manner to provide the optimum level of protection possible. Advance planning for new structures can achieve significant cost-savings by using inexpensive materials which can perform dually as both structure and armor, minimizing the use of expensive steel armor to supply the needed protection. This analysis shows that many load-bearing structural materials also perform well as armor.

The ballistic properties of various materials often used in construction were tested against a number of projectiles. Table 12-2 compares the muzzle velocities of the projectiles and lists the PBL V_{50} determined for the materials tested. The results of the tests indicate, for example, that an 8-inch-thick hollow concrete block wall resists penetration by an M193 ball projectile but can be penetrated by an M2 armor-piercing (AP) projectile. However, an 8-inch-thick fully grouted concrete block wall should provide PBL V_{50} protection against a .30-caliber M2AP projectile.

Mild-steel, rolled-homogeneous steel, or high-hardness steel plates can be added to existing structures to provide V_{50} protection if existing walls, footers, etc., can bear the additional weight. Table 12-3 indicates the steel plate sizes which can be used to provide PBL V_{50} protection against the listed projectiles.

Improving the protection of existing structures is only a function of the choice of materials and the method of attachment. Some opaque lightweight armor materials have been tested at Sandia National Laboratories to determine their small arms PBL V_{50} (Table 12-4). These tests showed that, in most instances, the thickness of the samples supplied by the vendor was not adequate to give V_{50} protection for the projectiles tested, i.e., PBL V_{50}

TABLE 12-2

Ballistic Properties of Walls

Weapon Caliber Projectile Weight PMV	M1 .30 M2 AP 166 gr 2765 ft/s	M14 7.62 mm M80 Ball 149 gr 2750 ft/s	.30-06 .30 SP 220 gr 2410 ft/s	M16 5.56 mm M193 Ball 56 gr 3185 ft/s
Wall				
No. 1 8-inch hollow concrete block	<1533 (P)[a]	<1567 (P)	1409 (P)	>3565 (NP)[b]
No. 2 8-inch filled concrete block	>2990 (NP)	>3086 (NP)	>2682 (NP)	>3606 (NP)
No. 3 4-inch face brick	1864 (P)	>3086 (NP)	>2670 (NP)	>3569 (NP)
No. 4 2-inch concrete T-beam	1887 (p)	2738 (P)	1935 (P)	>3488 (NP)
No. 5 4-inch reinforced concrete	>3139 (NP)	>3060 (NP)	>2673 (NP)	No test required
No. 6 8-inch reinforced concrete	No test required	No test required	No test required	—
No. 7 12-inch reinforced concrete	—	—	—	—

PMV = Published muzzle velocity
[a](P) denotes complete penetration
[b](NP) denotes no (partial) penetration

TABLE 12-3

Ballistic Properties for Mild Steel (QQ-S-741D)

Weapon Caliber Projectile Weight PMV	M1 .30 M2 AP 166 gr 2765 ft/s	M14 7.62 mm M80 Ball 149 gr 2750 ft/s	.30-06 .30 SP 220 gr 2410 ft/s	30-06 .30 SP 125 gr 3140 ft/s	M16 5.56 mm M193 Ball 56 gr 3185 fts/	.30-06 .222 SP 55 gr 4050 ft/s
Thickness						
3/16 inch	No test	1634	1435	1604	1860	1776
1/4 inch	<1400	1887	1758	1833	2206	2181
3/8 inch	1699	2429	2172	2593	3282[a]	3210
1/2 inch	1862	2726	2537[a]	2838	3659	3680
5/8 inch	2118	3217[a]	2849	3550[a]	No test	No test
3/4 inch	2207	>3535	3200	>3635	>4189	4116[a]
1 inch	2765	—	—	—	—	—
1-1/4 inches	3158[a]	—	—	—	—	—

PMV = Published muzzle velocity
AP = Armor-Piercing
SP = Soft Point
[a]Recommended Thickness

TABLE 12-4

Ballistic Properties of Some Opaque Lightweight Armor Materials[a]

Armor Material	Approx. Thickness (inches)	Areal Density (lbs/ft²)	Approx. Cost ($/ft²)	Weapon Caliber	Projectile Characteristics[b]	Muzzle Velocity (ft/s)	PBL V_{50} (ft/s)
Aluminum (2024-T3)	0.19	2.7	5.0	.38 Special	150 gr MP	1060	1232
				.357 Magnum	158 gr SP	1550	1198
				9 mm	116 gr FMJ	1450	1272
				.44 Magnum	240 gr SP	1470	1090
Flightweight I® fiberglass composite[c]	0.25	2.5	12.5	.38 Special	150 gr MP	1060	1242
				.357 Magnum	158 gr SP	1550	1382
Flightweight II® fibergalss composite[c]	0.38	3.5	15.5	.44 Magnum	240 gr SP	1470	1646
Plywood/Aluminum (2024-T3) composite	0.75/.19	4.4	5.5	.44 Magnum	240 gr SP	1470	1155
Kaisaloy®[d]	0.25	10.2	3.7	.223 M16	56 gr M-193 Ball	3185	2767
Kaisaloy®[d]	0.38	15.3	5.6	.30-06	166 gr M2, AP	2765	2382

[a]Data from Sandia tests
[b]MP = Metal-Piercing
SP = Soft Point
FMJ = Full Metal Jacket
AP = Armor-Piercing
[c]Product of Protective Materials Co.
[d]Kaiser Steel Co.

was less than the muzzle velocity. A comparison of the penetration data for equal thicknesses of material indicates that steel is more effective in stopping rifle ammunition. The use of fiberglass or aluminum alone as armor generally restricted to use against handgun or small-grenade attack.

One of the goals at Sandia National Laboratories was to find a lightweight (15 lb/ft² maximum) armor that would prevent penetration by .30-caliber AP projectiles. Two ceramic composites were found which have this capability: an alumina composite and a boron/carbide fiberglass composite. (Table 12-5). The high cost of the boron/carbide fiberglass composite armor would probably prohibit its use in many fixed-site applications; however, the alumina composite is competitive in cost with the steel armors and provides an equivalent level of protection. The PBL V_{50} rating given the ceramic materials means that no penetrations occurred in any of the samples tested. Table 12-5 indicates that all the tested materials in the thicknesses listed will give good protection against Class I, II, and III weapons.

Methods of fastening or mounting metallic armor to a structure encompass all the conventional techniques used in the construction industry. When the functions of armor and structural support are combined, structural loads should not exceed good engineering standards based on the tensile and yield strengths of the material.

Steel armor is susceptible to corrosion and stress cracking. Welds on hard surface steels often become soft spots which are less resistant to projectile penetration than the rest of the steel armor; these welds also tend to aggravate corrosion and cracking. However, a zinc chromate coating on scale-free surfaces, followed by a coating of epoxy resin or epoxy-based paint, will protect armor for several years in a normal environment.

Special care is needed in handling ceramic composites to preclude cracking or chipping the ceramic. Mounting or fastening techniques which prestress the ceramic greatly degrade its protective capability. Compressive clamping of fiberglass should be voided. Fastening bolts or screws into fiberglass threads is a totally unreliable method of attachment. Tapped metal inserts should be bonded or molded into the fiberglass.

All of the materials listed in Tables 12-4 and 12-5 are expensive. For this reason, their use would probably be

TABLE 12-5

Comparative Lightweight Armor Protection .30-caliber AP Projectiles[a]

Material	Areal Density (lbs/ft²)	Approx. Total Thickness (inches)	Material Cost ($/ft²)	Protection Level
Alumina composite[b]	15	—	28	V_0[c]
Boron carbide/ fiberglass composite[d]	7	0.58	300	V_0
Rolled homogeneous steel[e]	25	0.61[f]	17	V_{50}[g]
High-hardness steel[h]	21	0.51[f]	10.5	V_{50}

[a]Velocity of approximately 2,760 ft/s
[b]Reference Sandia Laboratories Report, SAND76-0655, July 1977 (CNSI)
[c]Based on a sample size of 13. A V_0 rating means that no penetrations occurred on any of the samples tested.
[d]Manufactured by Norton Company, Worcester, Massachusetts
[e]Per Mil-S-12560
[f]*Ballistic Technology of Lightweight Armor*, AMMRC Technology Report No. TR-73-47, November 1973 (CNSI)
[g]The velocity at which 50 complete penetrations and 50 partial penetrations can be expected. (Refer to Armor Specifications in appendix B of this chapter.)
[h]Per Mil-S-46100

limited to such items as doors for gatehouses and guard posts, vehicles for transporting or escorting shipments of special nuclear materials (SNM), and protective shields for communications equipment and other critical hardware. Whenever possible, concrete, combinations of concrete and steel, or other construction materials should be used for the protective walls of structures.

Transparent Armor

Transparent armor consists of a highly specialized, limited class of materials. For many years, it was common practice to merely increase the thickness of ordinary glass to increase its protection capability. This caused problems of distortion and loss of transparency. The discovery of laminated, prestressed (safety) glass was the beginning of a new era for bullet-resistant transparent composites. Concurrent with this development, transparent plastics, i.e., Lucite® and, much later, Lexan®, became popular because of their impact resistance. Unfortunately, Lucite and Lexan are susceptible to scratching, chemical etching, and crazing if they are used as outer surfaces exposed to normal exterior environments. Most transparent armors marketed today take the form of a composite glazing which uses the transparent plastics as inner layers with external layers of float glass or safety glass. These composites provide good protection against handgun and small-grenade attacks with very little distortion or loss of transparency. Table 12-6 provides data on the PBL V_{50} of transparent armor materials.

The edges of laminated, transparent armor should always be sealed to prevent oxidative discoloration of the bonding agent and fogging due to interlaminar moisture penetration. The exposed surface of the plastic layer should also be coated with a hard chemical-resistant film to improve its durability. Structural loading or highly localized stresses on the armor must be avoided. Stress caused by the difference in the thermal coefficients of expansion of the framing material and the armor can be eliminated by mounting the armor in a soft rubber channel (approximately 0.12-inch wall thickness).

As shown in Table 12-6, the total layered thickness of the transparent armor materials must be close to 1.5 inches in order to prevent the penetration of Class II (rifle ball) ammunition. All the materials listed in Table 12-6 are available from commercial sources; however, no known commercially available transparent armor with good optical properties can stop Class III AP projectiles. A transparent alumina armor developed by Sandia Laboratories does provide this kind of protection, but the estimated material cost is $1300 per square foot.

TABLE 12-6

Ballistic Properties of Transparent Armor Materials[a]

Armor Material	Approx. Thickness (inches)	Areal Denisty (lbs/ft²)	Approx. Cost ($/ft²)	Weapon Caliber	Projectile Characteristics	Muzzle Velocity (ft/s)	PBL V_{50} (ft/s)
Lexan® sheet[b]	0.50	3.2	11.6	.38 Special	150 gr MP	1060	831
Lexguard®	1.00	6.4	25.2	.44 Magnum	240 gr SP	1470	1354
	1.25	8.0	29.4	.44 Magnum	240 gr SP	1470	1556
Flightweight IIT[c]®	1.44	10.1	35.0	.44 Magnum	240 gr SP	1470	>1887
	1.44	10.1	35.0	.223 M16	56 gr M193 Ball	3185	2575
Flightweight IIIT[c]®	1.88	14.2	—	.223 M16	56 gr M193 Ball	3185	3543
	1.88	14.2	—	.30-06	152 gr M2 Ball	2800	2436
Safety glass/Lexan®	0.38/0.38	7.5	14.6	.44 Magnum	240 gr SP	1470	1618
composite	0.38/0.50	8.2	17.5	.38 Special	150 gr MP	1060	>1998
	0.38/0.50	8.2	17.5	.44 Magnum	240 gr SP	1470	1685
	0.38/0.50	8.2	17.5	.223 M16	56 gr 193 Ball	3185	2354
Safety glass/ Lexguard®	0.38/1.0	11.0	31.0	.223 M16	56 gr M193 Ball	3185	2960
composite	0.38/1.25	13.1	35.2	.223 M16	56 gr M193 Ball	3185	3113
Safety glass	0.38/0.38/0.50	13.4	23.2	.223 M16	56 gr M193 Ball	3185	3580
(two layers)/Lexan® composite	0.38/0.38/0.50	13.4	23.2	.30-06	152 gr M2 Ball	2800	2451

[a]Data compiled by Sandia
[b]Product of General Electric Sheet Products Section, Plastics Business Division
[c]Product of Protective Materials Co.

Because of the high cost of these materials, their use has been limited primarily to armored vehicles. However, transparent armor in gatehouses and guard posts may prevent a serious loss of security personnel during a surprise attack on these installations.

Body Armor

Body armor has been used by law enforcement agencies for many years. During the Vietnam Conflict, an extensive research program was initiated to develop protective apparel for helicopter pilots. As a later follow-up, body armor for ground forces was included in this effort.

To be useful, the armor must be lightweight (preferably not over 8 to 10 pounds), comfortable, and nonrestrictive to body movements. Modern protective apparel which meets these requirements can provide personnel with full-torso protection against handgun and small-grenade attack. However, protection against higher energy rifle fire and artillery projectile fragments demands a considerable increase in weight, and, as would be expected, the heavier armor is more restrictive to movement.

The recent availability of high-strength fabrics made from Kevlar®* aramid fibers[6] provided a major breakthrough in light, flexible protective apparel. Ballistic data on this material are given in Table 12-7. Similar protection can be obtained from rigid vests made from polyester and nylon cloth prepreg laminates. Glass cloth epoxy prepreg laminates are also used in fabricating rigid vests, but these materials impose a significant weight penalty.

The protection level of flexible body armor can be enhanced appreciably by the insertion of flat plates of alumina ceramic. The use of a shingle-type overlay of small plates allows good flexibility for the torso, while larger plates can be used for thigh protection. Armor of this type will protect against rifle ball ammunition and artillery projectile fragments.

The cost of body armor is dependent upon the level of protection desired, the materials, and the method of fabrication. Vests resistant to a .38-caliber Special, a

*Product of E. I. duPont de Nemours Co.

TABLE 12-7

Ballistic Properties of Kevlar®[a] Flexible Body Armor[6]

	ARMOR CHARACTERISTICS		PROJECTILE CHARACTERISTICS			
Weapon	Areal Density (lbs/ft²)	No. of Plies[b]	Weight (grains)	Type[c]	Muzzle Velocity (ft/s)	PBL V_{50} (ft/s)
.22 Caliber	0.40	7	40	RNSP	1060	1142
.38 Special	0.40	7	158	RNSP	850	1030
.45 Caliber	0.40	7	185	JHP	950	897
.357 Magnum	0.86	15	158	SJHP	1250	1402
9 mm	0.86	15	124	FMJ	1120	1355
.44 Magnum	1.33	23	240	SJHP	1425	>1425

[a]Kevlar® 29, 1000 Denier 31 x 31 per inch, product of I.E. duPont de Nemours Co.
[b]Loosely tacked plies
[c]RNSP = Round Nose, Soft Point
JHP = Jacketed Hollow Point
SJHP = Semijacketed Hollow Point
FMJ = Full Metal Jacket

.45-caliber ACP, and .357- and .44-caliber Magnums are available for about $50. More sophisticated armor ranges in price from several hundred to about $500 per unit. J. Capps & Sons, Ltd., David Clark Co., Burlington Industries Fabric Co., and Protective Materials Co. are some manufacturers of conventional protective apparel.

CONCLUSIONS

A variety of relatively inexpensive materials can provide protection against small-arms fire and hand grenades. Very thick layers of steel or combinations of steel, earth, and concrete are required to prevent penetration by present-day missiles and artillery. The materials necessary to achieve the higher levels of protection are very costly.

In general, the choice of protection level necessary is determined by the class of the weapon to be protected against, as defined in the "Protection Class Level Criteria" (Appendix A). Once this level is established and an analysis has been made of the protective characteristics of existing or proposed structures, the requirement for additional armor, if any, will become obvious. If supplementary armor is required, ballistic information and cost data available from sources listed in this chapter provide a cost-effective means of choosing the appropriate material.

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APPENDIX A

PROTECTION CLASS LEVEL CRITERIA

The Protection Class Level criteria are intended to provide guidance to users of this handbook who are concerned with the purchase of armor or related protective materials. Table 12 A-1 provides classification data for various weapons based on caliber, projectile characteristics, and muzzle velocity. The protection class level desired for armor can be selected from Table 12 A-1.

It is recommended that materials requiring certification as to Protection Ballistic Limit (PBL V_{50}) be tested or certified in accordance with the proposed armor specifications in Appendix B.

TABLE 12-A1

Weapon Classification Data

Weapon	Projectile	Published Muzzle Velocity (ft/s)
CLASS I (SUBMACHINE GUN AND HAND GUN)		
.357 Magnum*	158 gr Metal Piercing	1410
.44 Magnum	240 gr Soft Point	1470
9 mm (Parabellum) Luger	115 gr Full Metal Jacket	1350
CLASS II (LIGHT ASSAULT AND SPORTING RIFLE)		
5.56 mm	56 gr Ball M16	3185
.222 Remington	50 gr Soft Point	3140
6 mm Remington	100 gr Soft Point	3130
.25-06 Remington	100 gr Soft Point	3050
.270 Winchester	130 gr pointed Soft Point	3110
.30-06*	125 gr Pointed Soft Point	3140
CLASS III (MILITARY RIFLE)		
.03-06*	166 gr Armor Piercing M2	2765
7.62 mm	156 gr Armor Piercing Type 53	2870 (COM. CHINA)
7.62 mm	169 gr Armor Piercing M1930	2768 (USSR)
CLASS IV (HIGH VELOCITY RIFLE)		
.220 Swift*	50 gr Soft Point	4110
.257 Weatherby	87 gr Soft Point	3825
.300 Weatherby	150 gr Soft Point	3545

*These weapons and projectiles are considered representative of their class and shall be specified for ballistic testing. They do not necessarily indicate the maximum threat of those listed in that class.

APPENDIX B

ARMOR SPECIFICATIONS

Purpose

This specification is proposed as a standard for armor acceptance.

Scope

This specification covers all materials to be used as armor for any structure or vehicle or as personnel body armor.

Requirements

The supplier shall certify that the armor provides a PBL V_{50} rating against the threat defined in the Request For Quotation (RFQ) or Purchase Order (PO).

A specification sheet defining any limitations as to weight, shape, mechanical or chemical characteristics, environmental requirements, etc., shall be a part of the RFQ or PO.

The material supplied shall be defined by the supplier or as specified in the RFQ or PO. Each item shall be marked with the manufacturer's name, trademark, or lot number of the finished products to identify the material used.

All test samples shall be full pieces of armor randomly selected from the same lot number of finished products or separate test pieces of the same lot or heat-treat group of that material defined in the RFQ or PO. A minimum of two test samples (24 by 24 inches) shall be provided for each specific weapon certification test.* Test samples

*The size of some finished products may not meet this criterion and shall be exempted in the RFQ or PO.

and copies of associated data and records shall be transmitted to the purchaser.

In the event of conflict with other directives, the requirements specified in the purchase order shall have precedence.

Ballistic testing may be waived by the purchaser if records of tests of material from the same lot or heat treat group are presented by the supplier and are deemed acceptable.

Ballistic Testing Definitions

Protection Ballistic Limit (PBL V_{50})

There are several methods used to measure the resistance to penetration of armor. These methods include the Army, Navy, and Protection Ballistic Limits used in the United States, the critical velocity method used in the United Kingdom, and the critical angle method used in the Federal Republic of Germany.

The criteria for determining the PBL V_{50} used in this specification are illustrated in Figure 12-1 and defined as the average of six fair impact velocities comprising the three lowest velocities which result in complete penetration and the three highest velocities which result in partial penetration. To achieve the above requirements, a maximum of 15 consecutive rounds is permitted. A maximum spread of 125 ft/s is permitted between the lowest and highest velocities employed in the determination of the ballistic limit.

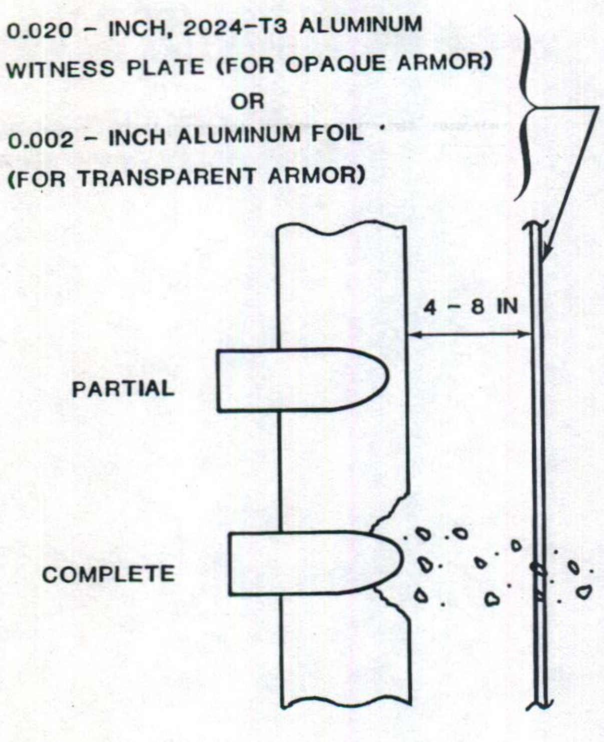


Figure 12-1. Protection Ballistic Limit Criteria

Partial Penetration

A partial penetration is defined as any projectile which impacts the armor with a fair impact and rebounds from the armor, remains embedded in it, or in which the projectile or fragment of the projectile or armor has insufficient energy to penetrate a 0.020-inch-thick witness plate (for opaque armor) or a 0.002-inch-thick aluminum foil (for transparent armor) located 4 to 8 inches behind the armor in a plane parallel to the target impact surface.

Complete Penetration

A complete penetration occurs when the projectile, fragment(s) of the projectile, or armor plate penetrates the witness plate so that light is visible through the perforations.

The critical velocity determined by a PBL V_{50} survey is that velocity at which 50 percent complete penetrations and 50 percent partial penetrations can be expected.

Fair Impact

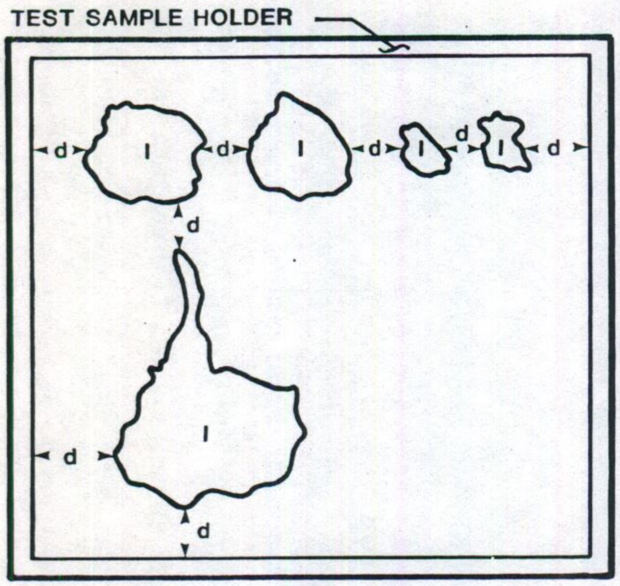
A fair impact results when an unyawed projectile strikes an unsupported area of the ballistic plate sample at such a location that there is at least 1 inch (6 inches for transparent armor) of undisturbed material between this impact and any previous impact, hole, crack, edge of plate, or spalled area (see Figure 12-2).

Unyawed Projectile

A projectile shall be considered unyawed when it strikes the test panel at such an attitude that its longitudinal axis is within 5° of its trajectory path. See item 7 (triggering devices) under "Ballistic Testing Equipment."

Angle of Obliquity

The angle of obliquity is the angle between the trajectory path of a projectile and a normal to the test material at the point of impact.



Legend:

I = Projectile impact point.

d = Undisturbed material between two impacted areas, between an impacted area and any hole, crack, edge of plate, or spalled area. Must be at least 1 inch for opaque armor and 6 inches for transparent armor.

Figure 12-2. Illustration of Fair Impact

Ballistic Testing Equipment

The following equipment is required for ballistic testing:

1. Gun mount — The test weapon or test barrel shall be firmly clamped to a gun mount, with the barrel horizontal, in such a manner that the alignment of the weapon or barrel is not altered by the firing.

2. Target frames — Large frames shall be used to rigidly support the test plate during impact and must be capable of being readily adjusted.

3. Test weapon or barrel.

4. Projectiles, propellant, and primed cartridge cases.

5. Witness plates — 0.020-inch 2024-T3 aluminum alloy sheets, and 0.002-inch aluminum foil shall be used as witness plates.

6. Velocity measuring equipment — The ballistics tests shall be conducted with the use of equipment to record the velocity of the projectile. This equipment must be calibrated, and certification sheets must be furnished for the purchaser upon request. The measurement system shall provide the velocity of the projectile in feet per second as it passes two detection points to an accuracy of 0.2 percent.

7. Triggering devices — The dimensions listed below may be varied slightly to fit individual conditions and range instrumentation, but the accuracy of the measurements must be maintained. The triggering devices shall define planes perpendicular to the line of flight of the projectile. One such device shall be located approximately 4 feet and an other approximately 10 feet from the muzzle of the test weapon or barrel. The distance between the devices shall be measured within an accuracy of 0.01 inch.

8. Yaw cards — Yaw cards shall be located 12 inches in front of the point of impact. Savage wide tonepaper or its equivalent shall be used.

9. Data record cards.

10. Muzzle blast deflector — A panel of wood or steel (as appropriate) with a small projectile clearance hole (2 to 3 inches in diameter) may be erected perpendicular to the projectile trajectory between the weapon or barrel muzzle and the initial velocity triggering device as a muzzle blast deflector to prevent "false triggers" from muzzle blast.

Ballistic Testing Records

In addition to the ballistic data to be recorded, the following items are required:

1. Name of armor manufacturer,
2. RFQ/PO number,
3. Description of material, trade mark, or name (if material composition is of a proprietary nature) or lot identification number,
4. Ballistic test sample serial numbers, and
5. Test weapon or test barrel—type, caliber, and serial number, barrel length, number of lands and grooves of bore, and rate and direction of barrel twist.

Ballistic Testing Procedures

Conditions

All test samples shall be preconditioned to the environment specified for a minimum of 4 hours. Unless otherwise specified, the PBL V_{50} shall be determined at 0 ± 1° obliquity.

Test Procedures

1. Mount the test weapon or test barrel on a gun mount. Once the weapon or barrel is positioned and the triggering device aligned, do not move either until the test is completed.

2. Position target frame 16 ± 0.5 feet from the muzzle.

3. Position triggering devices.

4. Measure and record the following:
   a. Distance from muzzle to the first triggering device,
   b. Distance from the first to the second triggering device, and
   c. Distance from the second triggering device to the point of impact of the target frame.

5. Verify that line of fire is horizontal.

6. Position witness plate.

7. Position yaw card.

8. Record the following:
   a. Ambient temperature and humidity,
   b. Test material environmental exposure conditions,
   c. Propellant type and lot number, and
   d. Projectile manufacturer type and weight.

9. Mount the test sample on the target frame. Tests at other than ambient temperature must be conducted with a minimum of delay.

10. Adjust the target frame so that the test material is at 0 ± 1° obliquity both vertically and horizontally.

11. Determine PBL V_{50} as follows:
    a. Fire the designated projectile at the target at a velocity estimated to be the ballistic limit.
    b. Inspect the test material and witness plate.
    c. Record the following:
       (1) Propellant weight,
       (2) Projectile velocity—average measured between screens,
       (3) Type of penetration,
       (4) Damage to test material (lengths and widths of all spalling and lengths of all cracks),
       (5) Condition of witness plate,
    d. Move the test sample so that the next round will impact in a "fair" area.
    e. If the first round yields a complete penetration, fire the second round to provide an approximate 100 ft/s lower velocity in an at tempt to obtain a partial penetration.
    f. If the first round yields a partial penetration, fire the second round to provide an approximate 100 ft/s higher velocity in an attempt to obtain a complete penetration.
    g. Continue this up and down method until at least three complete and three partial penetrations, having a velocity spread not greater than 125 ft/s, have been obtained. After one complete and one partial penetration have been achieved, the velocity increment changes shall have less than 50 ft/s difference from the last projectile velocity.
    h. Calculate the PBL V_{50} by taking the arithmetic mean of the three lowest velocities producing complete penetration and the three highest producing partial penetration, having a velocity spread over the six velocities not greater than 125 ft/s.

CHAPTER 13

DISPENSABLE BARRIERS AND DETERRENTS

INTRODUCTION

Physiological design factors can be used to deter, delay, or disrupt adversaries. Deterrents can be designed for direct interference with sensory and motor processes in addition to adding physical encumbrances. These deterrents include visual obscurants and chemical agents which create a hostile environment. Social acceptance may prevent the installation of systems that would automatically inflict permanent, serious, bodily injury on an adversary. The dispensable barrier technology described in this chapter affords methods of augmenting protective structures to provide high levels of protection.

DISPENSABLE MATERIALS

Actively dispensable denial materials are materials which are used as a complement to massive physical barriers in order to defeat or to delay adversaries. A permanent, massive physical barrier can sometimes be defeated by a single attack mode. There are, for instance, demolition tables available in the open literature that show how to calculate the charge size required to breach any thickness of reinforced concrete. Any number of barriers constructed of similar materials can be breached by similar methods. However, if the permanent barriers are augmented with reinforced rigid or sticky foams and an offensive irritant agent, the adversary must be prepared not only to breach the barriers but also to remove the foams and cut and remove the reinforcement, and he must conduct these operations while dressed in personal protective gear.

To be adequately prepared to be successful in a short time, the adversaries must have prior knowledge of the additional materials they will encounter. Actively dispensable materials offer the defensive advantage of being unavailable for identification and detailed inspection before an attack actually begins.

It has been suggested in other security improvement programs that the psychological impact of some deterrents may be cost-effective. A detailed review of the suggested deterrents reveals, however, that the expected psychological effects are highly variable with individuals and cannot be relied upon. A search has been made of the available literature to find commercial products that are effective. Few products currently available were judged to be sufficiently effective to be included here.

Available materials that can be dispensed at the time of an attack may be sufficiently tough to cause lengthy delays in attacks in which only human physical strength is used. These same materials, however, can often be readily removed with vehicle-mounted power equipment. Therefore, their effectiveness is dependent upon other parts of the barrier system as well as upon their own properties. In particular, their effectiveness is dependent upon the control of vehicle access to the site of the material deployment. However, inner chambers of a facility are not usually accessible to vehicles.

Materials suitable to accomplish burdening include rigid plastic foams, sticky plastic foams, sticky sprays, slippery sprays, and rubble piles. Reinforcement of the foams with metal nets, barbed tapes, or container tie-downs increases the difficulty of removal; however, some of these items may not be automatically dispensable.

An adversary's ability to perform work may be decreased through the use of visual obscurants, sound which masks communication, and physiological (irritant) agents. Obscurants are effective because they reduce an adversary's vision, causing him to (1) take additional time to figure out what he must do to succeed, (2) restrict attack modes so as not to accidentally injure essential fellow team members, and (3) consume additional time troubleshooting equipment problems that arise on the scene and improvise solutions. Obscurants also require the use of personal protective gear.

Materials that are effective as obscurants include pyrotechnic smokes, fog oil smokes, nonpyrotechnic smokes, and aqueous foams. Techniques for generation of pyrotechnic and fog oil smokes well-known from military literature. Nonpyrotechnic smoke dispensing technology is also quite well-known at this time. High-expansion aqueous foams are well-known in the fire-fighting equipment field. These aqueous foams may also be used to carry physiologically active agents.

Communication between adversary team members is a vital function if any unforeseen obstacles or complications arise during the adversary attack. With recent advances in portable radio transmitters, it may not be possible to totally mask oral communication between properly equipped persons, but at least one sound system is available that effectively masks communication between persons who are not equipped with transmitters.

The choice of physiologically active agents is probably restricted to the irritants CS (ortho-chlorobenzalmalononitrile) and CR (dibenzoxazepine). The effect of these agents upon humans is either temporary incapacitation or physical encumbrance, depending upon whether or not personal protective gear is worn. Temporary incapacitation is the desired effect; however, if the adversary comes prepared and is dressed in protective gear, he is encumbered. If he is required to work vigorously for 30 to 45 minutes in an impervious suit using a full face respirator, he will be incapacitated due to heat exhaustion. The materials that are identified here are effective in small doses and also possess large safety factors.

Irritant agents primarily affect mucous membranes and the wet areas of the body. Since these agents are effective at sensory nerve endings, they have onset times on the order of 5 to 15 seconds. The effects of a single exposure typically last for 10 to 20 minutes. Irritants may temporarily incapacitate an adversary by causing intense skin and eye pain and tightness of the chest.

Much interest has been evinced in a class of agents broadly termed "psychological stressors." These are agents that can impair behavior without direct physical contact with the subject and include a variety of sensory stimuli such as lights, sounds, and odors. The experimental literature available in these areas has been reviewed, and some experiments have been conducted to determine the potential value of psychological stressors in security applications.

The concept of flickering lights as a debilitating agent has received considerable attention ever since it was observed that intense lights flashing at certain rates could apparently induce epileptic seizures in some people. Actually, a small number of epileptoid persons can be "driven" into mild seizure states by flashing lights, but the general populace is unaffected, except for minor discomfort due to the limited intensity of the lamps used in most experiments. Well-controlled experiments revealed that certain types of performance could be adversely affected by flicker, but only if the subjects were burdened to maximum capacity on the particular task being measured. Other tasks were unaffected.

The anecdotal reports of gross perturbation of behavior due to flickering lights have not been confirmed in any of the numerous laboratory studies conducted. Since the real-life situation does not allow for the degree of control over the subjects that is maintained in a laboratory experiment, flicker is not considered a cost-effective denial technique.

The use of sound as a stressor has also been the subject of speculation and anecdotal reports. A number of popular reports about the use of "infrasound" as a weapon have been particularly imaginative. Almost all of the popular references to "infrasound" were actually describing low-frequency, mechanical vibration rather than sound. There is only one facility in the United States for the generation of very low frequency sound waves. This facility is the NASA-Langley Research Center Low Frequency Noise Facility. Although their device, which consists of loudspeakers with a cone diameter of 14 feet, can cause discomfort, it is obviously not a feasible means of impeding the work of adversaries. Similarly, the use of ultrasound (sound above 20 kHz) is not effective in perturbing behavior.

Within the audible spectrum, at the mid-frequencies (1 to 3 kHz), intense sounds are very effective at disrupting communication and, if levels above 135 dB can be generated, the sound can be painful. These effects can be neutralized by the use of ear defenders. However, if the adversary is forced to wear ear defenders in the course of the attack, this in itself may serve to impede performance.

The use of malodorous substances as stressors has been tested. Although such substances can be very offensive, their effects vary greatly among individuals and would not disrupt the performance of a determined adversary.

All of the items discussed in detail are considered usable in fixed-site protection systems.

SAMPLE SYSTEM

Before giving a detailed evaluation of individual denial items, a sample system will be discussed to illustrate the complementary roles played by several deterrents in an integrated system.

For discussion purposes, assume that denial of access to a vault is required. Assume further that permanent physical barriers exist around the vault sufficient to provide adequate delay except for a hallway approach to the vault door. The problem then is to impede access to the vault door by means of the access hallway. The hallway is assumed to be 2 metres wide by 3 metres high and 5 metres in length. This represents a volume of 30 cubic metres and a floor area of 10 square metres.

First, two steel-grid metal gates can be installed at 2 metres and 4 metres, respectively from the vault door. Each of the gates could cover the entire cross section of the hallway. Penetration-resistant doors could also be installed at the end of the hallway opposite the vault door. The actively dispensable elements which could be used in the system are sticky foam, rigid foam, and irritant agent CR in solution. Sticky foam could be dispensed directly onto each steel gate. Enough material should be dispensed to completely cover the gate and restrict the flow of incompletely reacted rigid foam. Rigid foam could be dispensed between the two sticky-foam covered gates, and between the second gate and the vault door. Sufficient rigid foam should be used to completely fill these voids. At the same time, irritant agent CR in solution could be continuously sprayed in a light fine mist between the penetration-resistant doors and the first gate.

If the adversary is not wearing a respirator mask and water-impermeable suit when he breaches the penetration-resistant doors, the irritant agent will incapacitate him with eye, skin, and respiratory system pain. If, however, the adversary has anticipated he use of such agents and is equipped with a protective suit, he must now remove the semirigid foam, the sticky foam, and the steel gates before he can attempt to breach the vault door. Working with hand and portable power tools and small explosives, two men will consume perhaps 60 minutes in reaching the vault door. Effort must still be expended on breaching the vault door. However, the heat stress imposed by the water-impermeable suit will, by this time, have incapacitated the adversaries.

DISPENSABLE DENIAL MATERIAL EVALUATION

Evaluation of actively dispensable denial materials has been applied to criteria relevent to system integration. These criteria include

1. Specific manner of use,
2. Denial effectiveness,
3. Cost
   a. Development,
   b. Procurement, and
   c. Maintenance,
4. Premature hazards,
5. Operational hazards,
6. Recovery operations, and
7. Social acceptance
   a. Employee,
   b. Community,
   c. Institutional, and
   d. Legal.

Rigid Foam

The primary candidate rigid foam materials are 32- to 48-kg/m^3 polyurethane foams. These materials are stored as two separate reactive chemicals which foam on mixing. Dispensing and curing can be accomplished in a few minutes. Properly optimized, these foams are quite tough when cured. The expansion ratio of foams of this density is approximately 30 to 1, from the stored system to the deployed system.

The primary uses of rigid foam in denial systems are to block passageways and to make a protected item integral with its containing structure on command, i.e., to encapsulate the protected item.

A large number of polyurethane foam formulations are commercially available. For this reason, development requirements are involved only with evaluation and selection. The foam material cost is approximately $50 per cubic metre of volume to be foamed. Dispensing systems for two-component foams cost about $200 per cubic metre for a system which will fill 35 cubic metres. This cost is not linear with size. Larger systems could be much less expensive per cubic metre. Additional development and quantity fabrication could perhaps reduce the dispensing system cost to half the stated figure. System maintenance includes periodic sampling of the foam components to detect chemical degradation. Experience indicates that annual sampling is probably adequate.

Hazards that may affect adversaries include the chemical toxicity of one of the foam components, the possibility of entombment in the foam, and exposure to temperatures potentially as high as 130°C. The hazards occur only if the adversary is present during dispensing and remains in the area. Once the foam has cured, the only hazard is overcommitment to his goal which may drive him to physical exhaustion. Hazards presented to operating personnel in case of premature actuation could be similar; however, the foam can be dispensed slowly enough that those persons should have time to leave the area before any severe effects result. In addition, the activation system could employ a short time-delay following a warning signal.

Recovery operations necessary after the dispensing of rigid foams include removal of the foam, perhaps with a chain saw and shovel, and sand blasting.

Sticky Foam

A nonhardening sticky foam has been developed as a barrier. This foam has an expansion ratio of approximately 30 to 1 and exhibits a final density of nearly 27 kg/m^3. It maintains its original deployed volume for at least 4 hours. Since this foam is nonhardening, it collapses after a period of time. The material is aggressively tacky and becomes tougher when collapsed.

The intent of the use of sticky foam is to foul tools and to cause intruders to become entangled in the foam and stick to themselves and their equipment. Figure 13-1 shows a sequence of photos in which an attacker attempts to remove a sticky-foam-covered store.

The sticky foam material costs approximately $41 per cubic metre of volume to be filled. The dispensing system cost is approximately $120 per cubic metre of volume to be protected. This dispensing system can probably be decreased to $70 per cubic metre with additional development and quantity fabrication. Development of a usable sticky foam is complete, and dispensing hardware also exists.

The only hazard to either adversary or operational personnel is the possibility of their becoming sufficiently covered with the material that they can no longer breathe. The intruder may get into this situation by being present during deployment, by an overcommitment to his attack, or by falling. Operational personnel may be exposed to the material as a result of premature deployment, but careful system design should lower the probability of such an occurrence to an acceptable risk level.

Recovery operations after deployment of sticky foam include removal of the material by mixing with vermiculite, by steam cleaning, and by washing with a solvent.

Sticky Spray

Sticky spray is defined as the active spraying of a viscous material prior to and after entry of an adversary into a protective structure. The intent of using this spray is to cover protected items and adversaries with a layer of very sticky material that will impede efforts to remove the protected items. The effectiveness of this system is expected to be high. Adversary simulation testing has shown that sticky materials are among the most difficult mechanical deterrents with which to deal.

An acrylic resin has been identified that costs approximately $3.50 per square metre of surface to be sprayed. A dispensing system has not yet been developed.

Maintenance cost for a sticky spray system should be low. Periodic testing of the chemicals to be sprayed should suffice as a maintenance procedure.

Hazards that occur as a result of being sprayed with this material are primarily caused by the mechanical problems that arise as a result of being covered with sticky resin. Two other hazards which are exceptions are (1) getting sticky resin in the eyes and (2) massive exposure to chlorinated solvents used in the compound and in cleanup.

Figure 13-1. Sticky Foam

Recovery operations include resin removal with solvents and steam cleaning. No experience has yet been gained in cleaning up sticky spray, and such an operation might prove difficult.

Slippery Material

A commercial material known as "Super Slip" or "instant banana peel" is advertised as an aid in denying an area to rioters. The material is a high molecular weight, water-soluble polymer which is dispensed as a powder over the area to be made slippery. As long as the powder remains dry, it is not slippery; however, when water is introduced, the material quickly becomes very slippery and remains slippery as long as it is wet. It can be allowed to dry and be reused in the same place by another application of water. For disposal, the material can be peeled up after it has dried or it can be hosed away with water. The material apparently must be used on a smooth surface. Such slippery material may be effective outside a structure on an inclined, smooth surface where it impedes approach to the structure itself.

One manufacturer states that it is impossible for anyone to walk across a 10- to 15-metre-wide area covered with activated "instant banana peel" and return with a moderately heavy item. The primary hazard to persons attempting to walk on this material is the risk of injury due to a fall.

At one supplier's recommended rate of application, 1 kg of "instant banana peel" would cover approximately 2000 to 5000 square metres. No dispensing system has been designed; however, it might be possible to use a system similar to a fire-fighting sprinkler system with the slippery material added to the water through a venturi. In this application, the material could be stored as a concentrated solution.

Rubble Piles

Piles of heavy, nonhomogeneous rubble are difficult to remove by hand. This rubble may be deposited by having a hopper of material spill into a passageway or by explosively collapsing a specially constructed roof. By either of these means, massive amounts of rubble could be deposited, perhaps as "last ditch" measure. Piles of rubble could be effective in delaying intruders for hours.

Development cost of rubble systems should be minimal. The procurement of a rubble system will depend on whether a great deal of special construction is designed into the system. Hinged roof concepts for dispensing rubble are discussed in Chapter 10: "Earth Cover and Overburden."

If a combination of exploding bridgewire technology and out-of-alignment concepts are used in the explosives system, adequate safety should be achievable. The hazards created by such a system are falling rubble and the possibility of being buried in the ensuing pile.

Recovery operations that must follow system activation include removal of rubble, reconstruction of damaged buildings, and replacement of explosive actuators.

Obscurants

Obscurants include such materials as smokes and low-density aqueous foams. Smokes are finely divided, solid or liquid particles that are suspended in air. Military pyrotechnic literature describes many methods of generating smoke. Several types of smoke obscurants are available from suppliers of law enforcement munitions. Available smokes include Type C-HC pyrotechnic smoke, type FM nonpyrotechnic smoke, and fog oil smoke. HC smoke has received little attention because of its pyrotechnic nature. Fog oil smoke also has not been considered because of the type of generation equipment required. FM smoke combined with ammonia or amonium hydroxide, however, has some attractiveness as an obscurant. FM is the military designation for titanium tetrachloride. Combined with ammonium hydroxide, it produces titanium dioxide and ammonium chloride smoke particles. In the proper mixture, this smoke can be chemically neutral, which reduces corrosion problems. This smoke is very white and effectively obscures vision beyond 3 or 4 inches. Use of white or infrared light does not permit vision through the smoke. Military literature such as *AMCP 706-185, Engineering Handbook,* Military Pyrotechnics Series, Part I, Theory and Application, published by the U.S. Army Material Command contains further information regarding techniques of smoke generation.

Aqueous foams are widely used as a fire-fighting agent. These foams have densities in the range of 1.6 to 4.5 kg/m^3 and have the appearance of soap suds. Commercial foam generators are available that produce up to 1700 m^3/min.

The intent of the use of obscurants is to reduce or completely obscure the adversary's vision. This impedes the adversary's ability to carry out his task, especially if the task is significantly more complicated with reduced vision, and reduces his ability to communicate with other members of his team. Careful attention must be paid to the employment of obscurants in tactical situations to avoid screening the intruders from response force gunfire or apprehension.

Another use of obscurants is to enhance the effectiveness of entanglement devices such as barbed tapes and tie-downs. The aqueous foams may also serve as carriers for physiological agents.

It is impossible to state quantitatively the effectiveness of obscurants. Experience, however, indicates that obscurants enhance other deterrents and that obscurants by themselves are useful.

The cost of military-type smoke pots is quite low. For example, a 13.6-kg type C-HC Smoke Pot costs approximately $15. This device will generate smoke for 12 to 22 minutes and will obscure approximately 300 cubic metres. This type of smoke pot can be stacked so that successive pots in the stack burn serially, thus extending generation time.

FM and ammonium hydroxide smoke is not commercially available. Some development has been done at Sandia Laboratories, and the technology for dispensing these materials is quite well-understood at this time. The cost of an FM plus ammonium hydroxide smoke generator sufficient to initially obscure 100 cubic metres in 1 minute and then maintain that level of obscuration for 30 minutes is estimated to be $2,500. Figure 13-2 shows the Sandia-developed cold-smoke generator. Figure 13-3 shows a cold-smoke generation sequence.

Aqueous-foam generators are available in many sizes. An electric motor powered unit that generates 85 m^3/min costs approximately $600. The unit requires service water and foam surfactant which costs approximately $1 per litre. One litre of surfactant yields approximately 4.2 cubic metres of foam. Figure 13-4 shows aqueous foam being dispensed. The aqueous foam surfactant may require annual inspection and possibly will require replacement every 5 years.

Hazards are minimal if the area is evacuated immediately after obscurant generation begins. Persons who have breathed aqueous foam for 10 minutes have subsequently developed pneumonia. Other hazards caused by obscurants include the usual problems that arise when anyone attempts to move about without the aid of vision.

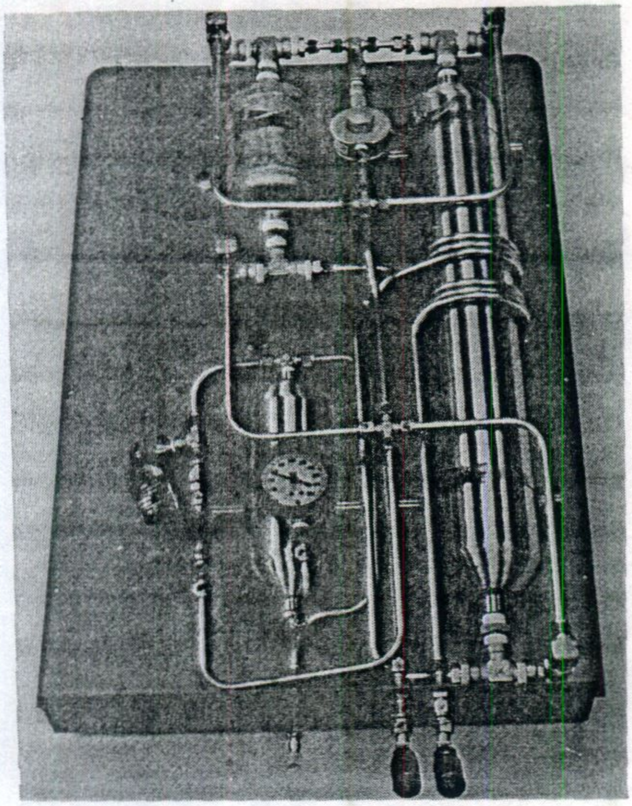


Figure 13-2. Cold-Smoke Generator

Operations to recover areas that have been filled with obscurants include ventilation to remove smoke, or waiting a few hours for aqueous foams to collapse, followed by washing to remove residue. The corrosive nonpyrotechnic smokes produced from liquid metal chlorides and/or ammonia will require additional recovery depending upon the type of equipment that has been exposed.

High-Intensity Sound

High-intensity sound has been used in police work for riot control and is an effective aid in mob dispersal efforts. Noise generators typically use electronic circuits and horn-type loudspeakers to generate mid-frequency noise (centered around 2 kHz) at offensively high levels (about 130 dB). The noise is effective in riot control because it interferes with oral communications and approaches the pain threshold of many people. Since mobs depend upon the verbal instructions of a charismatic leader, disruption of his speech links dissolves the coherence of the mob, facilitating restoration of law and order.

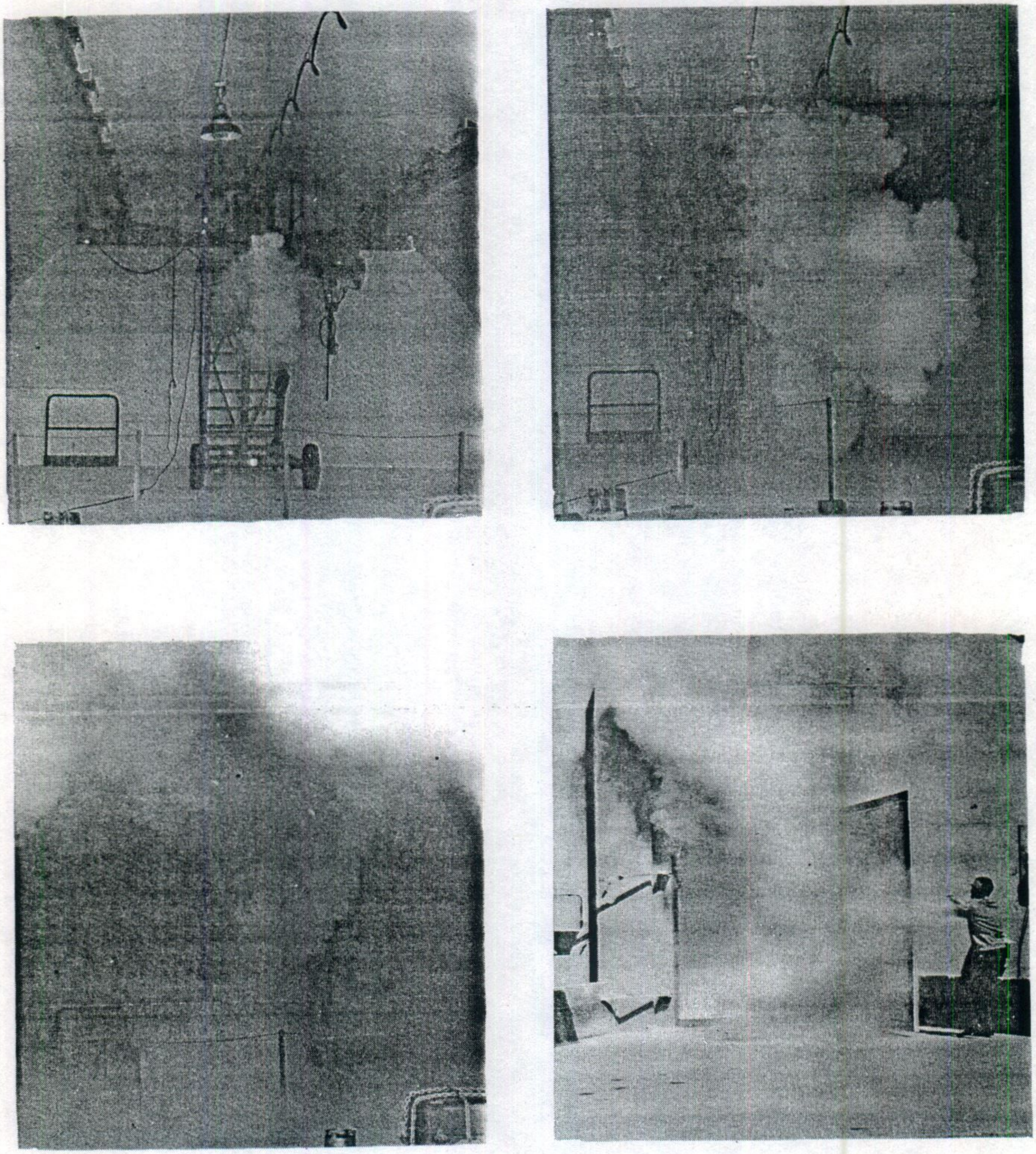


Figure 13-3. Cold-Smoke Generation Sequence

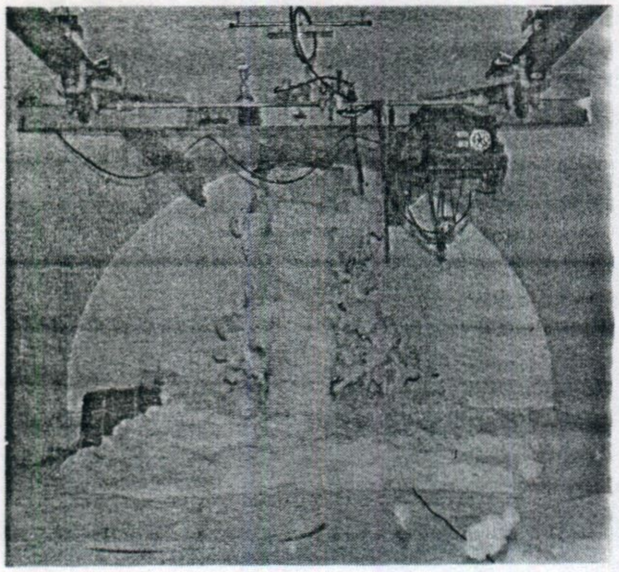


Figure 13-4. Aqueous Foam

A recently developed noise generator consists of two speakers driven by pulse generators. The pulse generators drive the speakers with high- intensity pulses at low frequencies (below 300 Hz). The speakers are operated at different frequencies. The output of the system is rich in harmonic and beat notes, generating noise throughout the audible spectrum and effectively masking all speech.

In the case of a determined violent attack, the coherence of an attack group will be unaffected by intense noise. However, adversaries would have to wear ear defenders since the sound levels considered (140 dB) would be intolerable. The ear defenders in themselves constitute an impediment to the wearers. A secondary effect on the adversaries is the complication of on-site communication since ordinary speech would be impossible. A system of radio transceivers is commercially available using in-the-ear microphone/earphones designed for use in high-noise environments. These devices do not work well in the presence of this noise generator. However, as is the case with ear defenders, the requirement for use of such transceivers, at a minimum, imposes additional complications upon the attackers.

The system is economical in its power requirements and is physically compact and easily concealed. Minimal development time is required to put this system into production, and procurement costs are expected to be modest. Maintenance requirements would involve periodic tests and battery checks.

No hazards are known in connection with this system. In case of premature activation, workers can cover their ears with their hands and leave the area.

Sensory Irritants

A sensory irritant produces a reversible physical incapacitation as a result of sensory stimulation following its contact with the skin, eyes, or mucous membranes. Examples of sensory irritants are lacrimators (tear producing agents), respiratory irritants, and some pain-producing substances. Since these act directly on the nerve endings, the pharmacological response is almost instantaneous. The lacrimators and respiratory irritants are effective primarily on direct contact with the eyes and respiratory tract. For this reason, it is essential that they be in the form of a vapor or an aerosol. The pain-producing substances act either on contact with the skin or subcutaneously, depending on the nature of the agent.

To illustrate the effects of irritants, consider CN (chloroacetophenone) and CS. These sensory irritants have been used in both military and civilian applications. Exposure of an unprotected individual to CN induces an immediate and copious flow of tears and intense eye pain. The reflex action of closing the eyelids and the profuse secretion of tears produces a suspension of vision that usually clears up within a few minutes in fresh air. The action of CS is faster and the effects are more profound than those of CN. Inhalation of air containing as little as one part per million of CS causes immediate incapacitation, characterized by severe burning of the entire upper airway and other respiratory distress, accompanied by reflex closing of the eyes, lacrimation, and a burning sensation in the moist skin on the face. These symptoms disappear within 5 to 10 minutes after the exposed person begins to breathe fresh air.

Irritant Agent CN

Irritant agent CN is mentioned here for completeness only. CN is the active agent in police tear gas and Mace®. Several cases of permanent eye damage and a few deaths are attributed to CN. For this reason, and because agents CS and CR are more effective and less of a toxic hazard, CN is not considered an acceptable agent.

Irritant Agent CS

Agent CS is a material that was developed for military use but has gained wide acceptance for use in civilian police work. CS is a powder that must be dispersed as an aerosol. The specific use of CS in a security system is to incapacitate adversaries with its severe irritant effects.

Agent CS is commercially available in many types of dispensers. One example is an irritant dispenser loaded with 60 grams of CS mixed with 60 grams of talc. This item can be purchased for approximately $40 and will deliver enough material to contaminate 850 cubic metres.

The symptoms and signs resulting from exposure to CS are characterized as follows:

1. *Eyes:* Intense burning or irritation with mild to severe inflammation of the mucous membrane which lines the eyelids.
2. *Nose and Throat:* Burning sensation in the nose and nasal mucous membranes and around the upper lip (especially if there is noticeable sweating), burning in the throat and dryness, and draining of the nasal sinus cavity.
3. *Chest:* A feeling of constriction in the chest, usually accompanied by a choking sensation and a feeling of suffocation.

Note that these effects are symptomatic only; no actual tissue damage occurs. The dosage that will incapacitate 50 percent of the people within 1 minute is estimated at 10 mg/m^3. The estimated LCt_{50} (dosage lethal to 50 percent of the people exposed) for a resting man who has inhaled CS is 25,000 mg •min/m^3 for exposures of up to 1 hour. The large safety margin between lethality and incapacitation is an important attribute of the usefulness of CS. The intensity of the symptoms varies with the concentration and the size of particles that are suspended in the air. Particles of the 4μm-size produce greater effects on the eyes, and the smaller particles produce greater nose, throat, and chest discomfort. In order for it to be effective, the CS aerosol must come in direct contact with the eyes and/or respiratory tract. Its vapor pressure is very low, and for this reason CS is not effective as a vapor.

Most persons wearing an ordinary organic vapor and dust gas mask will be protected from the effects of CS. Recovery from the physical effects of CS occurs in 10 to 20 minutes after an exposed person begins to breathe fresh air.

Irritant Agent CR

The intent in using Agent CR is to incapacitate adversaries with its severe irritant effects. CR is disseminated in an aqueous solution with propylene glycol and is effective in producing skin pain as well as eye and respiratory effects. Protection from CR requires an organic vapor gas mask and a water-impermeable suit.

CR has physical properties similar to CS. It appears to have a better safety ratio than CS and to be somewhat more active. Observations have been made on the effects of CR in weak solutions (up to 0.1 percent) on more than 150 volunteers. Splashed onto the face, these solutions cause pain, involuntary closing of the eyes, lacrimation lasting about 20 minutes, and reddening of the eyelid margins. There is no structural damage to the eye. In contact with the skin, CR causes pain that lasts for about half an hour. There is a burning sensation in the affected skin and a well-delineated reddening; sensitization does not occur. Solution entering the mouth causes a short-lived burning sensation, excessive salivation, sore throat, and mucous discharge from the nose. The general acute discomfort is accompanied by transient increase in blood pressure. These short-lived effects are not accompanied by the risk of long-term damage, such as that which may occur with the use of CN. Treatment is palliative and includes reassurance, removal of contaminated clothing, and washing of the eyes and skin. Eye pain can be relieved with medication.

CR is soluble in propylene glycol, which is relatively nontoxic, and can be generated as a spray from this solution. CR is a potent stimulator of sensory nerve endings in skin and mucosal surfaces, being effective in the eye, for example, at concentrations on the order of 0.00001 percent weight per volume (w/v). In addition, it has a low lethal toxicity for mammals when given by various routes of administration. For example, the oral LD_{50} for CR to various species lies between 600 and 7,000 mg/kg. This combination of potent irritancy with very low toxicity places CR into the class of compounds which may be chosen for use against law breakers, possibly by means of sprays or foam containing the material in solution.

The following account describes the effects following splash contamination of a man with dilute (0.01 to 0.1 percent w/v) solutions of CR in equal parts by volume of polyethylene glycol 300 and water, together with procedures recommended for the treatment of those so contaminated. It is based on observations made of more than 150 male volunteers.

1. *The Eye:* Dilute solutions of CR produce intense temporary irritation of the eye even when applied in small volumes. There is an immediate involuntary closing of the eyes and the individual is unable to undertake any coordinated action for a short time because of both pain and an inability to see. The latter is a consequence of closed eyes and excessive lacrimation. These effects generally persist for at least 15 to 20 minutes.

Shortly after the eye has been contaminated with CR solution, an individual demonstrates, in addition to closed eyes and excessive lacrimation, reddening and occasionally slight edema of the eyelids. The closing of the eyes and excess lacrimation usually do not persist for more than 30 minutes, and the effects on the eyelid linings and lids disappear within 2 to 6 hours. A small, transient rise in intraocular tension (internal pressure on eyeball) may also result.

2. *Skin:* Pain and reddening are the two main effects CR has on the skin. Within minutes, depending upon the thickness of the epidermis, rapid production of a burning pain occurs which may last between 15 and 30 minutes. This sensation is readily reactivated whenever the affected area is moistened. In these circumstances, it may recur in lessened form for several days.

   Accompanying the pain, there is intense reddening which has a well-demarcated edge corresponding exactly to the limits of the area of skin contamination. The reddening may persist for several hours but is less likely to recur at a later time than is the burning sensation in the skin.

3. *Treatment:* In view of the fact that the signs and symptoms produced by dilute solutions of CR are shortlived and self-resolving and since such solutions do not produce any tissue damage, treatment is symptomatic. Ideally, the person treating the patient should wear impermeable gloves, e.g., polythene disposable, to prevent his hands from becoming contaminated.

   If eye pain is still present when the patient is first seen, it can be considerably relieved by the instillation of 0.5 per cent amethocaine hydrochloride. This should be followed by irrigation of the surface of the cornea and conjunctival sac with isotonic saline. These procedures are all that are normally required since structural damage to the eye and its surrounding tissues does not occur, and secondary infection is very unlikely.

   The acute burning sensation felt in skin areas contaminated with solutions of CR starts to subside within 10 minutes, after which it is usually tolerable. The localized reddening, most marked for the first 30 minutes, usually disappears a few hours after contamination and does not call for treatment. The only procedure necessary is washing of the skin and hair with soap and water. The patient should be warned that the burning sensation may temporarily recur after each subsequent washing for a day or so. When washing the face and hair, care should be taken to prevent contaminated water from coming into contact with the eyes.

Agent CR is not commercially available in the United States at this time, although the major suppliers of tear gas munitions are aware of the agent.

DISPENSING SYSTEMS

Dispensing systems for activated delay materials must satisfy unique requirements. These requirements are

1. The systems must adequately disperse the dispensed material,
2. The systems must be capable of storing the dispensable material without significant degradation of either the material or the dispenser,
3. The systems must be capable of completing the intended sequence of functions, once initiated, without dependence upon externally supplied utilities,
4. The systems must function with high reliability after extended periods of inactivity and simultaneously possess low probability of premature activation,
5. The systems may have to be hardened to withstand the effects of violent breaching of the protected structure, and
6. The systems must be hardened to survive a sabotage attempt by an insider.

A thorough program of development and testing will be necessary to assure that these requirements are adequately fulfilled. The activation of these dispensing systems should be through the irreversible action of a one-shot device. This is to ensure that, once a system has been activated, it will perform its entire sequence of intended functions unless destroyed by direct attack. One such device is a high-reliability, explosively actuated valve.

The control circuit for this one-shot device may be actuated either through the action of a defender or through the output of an attacker-actuated sensing system. The choice of either of these options is dependent upon a systems analysis of the system under design properly integrated with local legal constraints.

SOCIAL ACCEPTANCE

The choice of denial agents must consider the acceptability of the agent from a number of social aspects, such (1) reaction of employees, (2) reaction of the community, (3) institutional considerations, and (4) legal considerations.

Reaction of Employees

An important factor in employee attitudes toward denial systems is the extent to which the system presents a hazard. There are indeed some risks to employees in case of premature activation of certain denial agents; however, the risk is small, and employee attitudes will be largely a function of how they interpret the risk. Given an understanding of the intended mode of operation of the denial mechanisms, there is no reason to expect undue apprehension about the denial agents. Industrial experience indicates that employees will accept risks with potentially far more serious consequences as part of everyday working conditions as long as the probability of the event is acceptably low. The mining industry is a well-known example of this. There are also many other occupations with a much higher probability of hazard, which are routinely pursued without undue apprehension, such as police work, construction work, etc. In view of the above, the relatively small risk of injury due to untoward activation of denial systems is not regarded as a negative factor in employee attitudes. However, relations with labor unions may present some difficulty.

Community Reactions

Ordinarily, community members are not unduly concerned about security methods if the methods do not have an adverse effect on the community. However, it is possible to elicit strong negative reactions to almost any methodology if an articulate emotional appeal is made.

Institutional Considerations

The organizations that will be administering the operation of the sites and vehicles where the denial agents are installed will naturally be concerned with all the criteria listed, and particularly concerned about denial effectiveness and premature hazards. Assuming that the systems are well-engineered, proper operation of the systems would be degraded only by abuse or neglect. Properly planned, the systems will be out of reach of ordinary work crews, and maintenance requirements should be minimal. The utilizing organization will have to establish administrative procedures to ensure periodic inspection and maintenance of the systems, but this is standard industrial practice for all types of high-reliability equipment and does not impose any unusual burden.

The possibility of premature activation of denial systems may cause concern since the consequences can be very costly if, for example, the rubble response is invoked. The foams and other agents are less costly but, if prematurely activated, could cause temporary pain for innocent employees, as well as necessitate the expense of cleaning up, recharging the systems, and causing the possible disruption of schedules. To allay concern about such eventualities, very careful attention necessarily must be paid to the human factor considerations in the design of the controls for these systems in order to preclude inadvertent activation without degrading system response or reliability. With the development of suitable control concepts, it is expected that the systems will be fully acceptable to the using organizations.

Legal Considerations

The use of barriers, obscurants, and physiologically active agents, such as irritant agents, is relatively new in industrial security work; however, the use of deadly force is an accepted practice for police and military security forces. There are, in any case, questions about the legality of the use of deadly force by private security forces. Since the use of rubble could be interpreted as the use of deadly force, legal opinions regarding authorization for such installations may be required in each state. With the exception of the rubble technique, it does not seem that the other techniques recommended will introduce any questions of legality. However, it is suggested that all aspects of any proposed systems be reviewed on a local basis for legal considerations.

REFERENCE

1. The data in these sections are abstracted from a report written for Sandia Laboratories by Dr. B. Witten, Chief, Chemical Research Division, U.S. Army Chemical Systems Laboratory, delivered October 16, 1974.

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Kane, John W. "Activated Denial Systems for Safeguards Application." *Journal of the Institute of Nuclear Materials Management*, 1979 INMM proceedings.

Witten, Dr. B., Chief, Chemical Research Division, U.S. Army Chemical Systems Laboratory. Report written for Sandia Laboratories. Delivered October 16, 1974.

CHAPTER 14

LOCKS

INTRODUCTION

This chapter contains a general description of key and keyless locks. It also describes the various methods used to defeat key locks and general information on ways to make key locks more resistant to defeat. The information is intended to allow security personnel to make more informed decisions on lock selection, installation, and inspection. More detailed information on locks can be found in the *Lock Handbook*.[1]

Locks are important elements in the overall delay system of a facility since they secure the movable portions of barriers. In all applications, lock delay capability should match the penetration resistance of the secured barrier. The delay time provided by locks varies with the type and sophistication of the lock. It is quite apparent that a barrier system is as weak as its weakest link. For example, a door that provides a 2-minute penetration delay ought to be equipped with a lock that also provides a 2-minute minimum delay.

LOCK VULNERABILITY CONSIDERATIONS

All locks can be defeated. No lock should be depended upon as a standalone means of physical protection. The delay time provided by a lock may be short due to lock design, operational procedures, administrative control, or procurement.

Lock Design

Successful, rapid, surreptitious defeat of a key lock usually requires a thorough knowledge of the construction of the specific lock that is being attacked as well as some level of attack skill. Special tools are frequently required. All locks are vulnerable to explosive and thermal defeat, both of which may require less time than does forcible defeat with manual or power tools.

Longer lock defeat time often results when several unique construction features are designed into the locking device:

1. A positively coupled key and deadbolt mechanism,
2. A nonaccessible key mechanism which restricts unauthorized extraction,
3. A highly pick-resistant key mechanism with antipick and decoding variations,
4. A hardened body, guard plates, and shields and a hardened or shrouded shackle and bolt, all of which have a substantial section thickness and cutouts with sweeping radii rather than sharp internal corners, and
5. Equivalent melting points for the key mechanism and the surrounding material.

Operational Procedures

Frequently, operating procedures intended to enhance security may inadvertently reduce security. For example, at times it is desirable to rekey a lock system expediently; however, this can be an extremely tedious and expensive task if a substantial number of locks are involved. One method of facilitating this task is to use locks which contain removable or interchangeable cores. Removable cores can be quickly and easily exchanged, but they can also jeopardize the whole locking system if the cores are vulnerable to quick, unauthorized extraction. Master keying (keying a set of non-keyed-alike locks to open with a common key) and keying alike (identical keying for several different locks) are often used. However, in both methods, the loss of a key or compromise of a lock may jeopardize the entire facility system.

Administrative Control

Control over all keys, removable cores, combinations, and locks that are used in a lock system should be rigidly maintained. Some cylinders require unique keys that are often key-controlled and duplicated at the factory only after proper key authorization and identification procedures have been followed. It would appear that better security could be attained if all keys were maintained internal to a facility.

Procurement

There are approximately 260 manufacturers involved in the production and/or marketing of locks and locking devices.* When placing an order for a locking device, it is imperative that the purchaser be thoroughly familiar with the product being purchased. In general, modification notations are not used by the lock industry. *The manufacturer retains the option of modifying the product without notice*. This is apparently done for either assembly ease, cost savings, or product improvement.

GENERAL DESCRIPTION OF LOCKS

Key Locks

Key locks are locks which operate through the use of a mechanical key. If the correct key is used, the key or the key mechanism retracts the bolt or latching mechanism and allows access. Most key locks fall into four general classes: warded locks, wafer (or disk) locks, pin-tumbler locks, and lever locks. In addition, key locks also include some unique options and variations of these general classes of locks. Each of these lock classes and their options and variations are discussed in the following subsections.

Warded Locks

Warded locks incorporate fixed wards or obstacles (external and/or internal wards) into the lock structure which a key must clear in order to rotate and operate the bolt or

*Established from the 1978 directory issue of the *Locksmith Ledger*, Vol. 38, No. 2, which contains a listing of these manufacturers.

latching mechanism. The key for a warded lock has ward cuts placed at the proper locations to allow key rotation. Figure 14-1 illustrates a typical warded lock with the correct key inserted and with an incorrect key inserted.

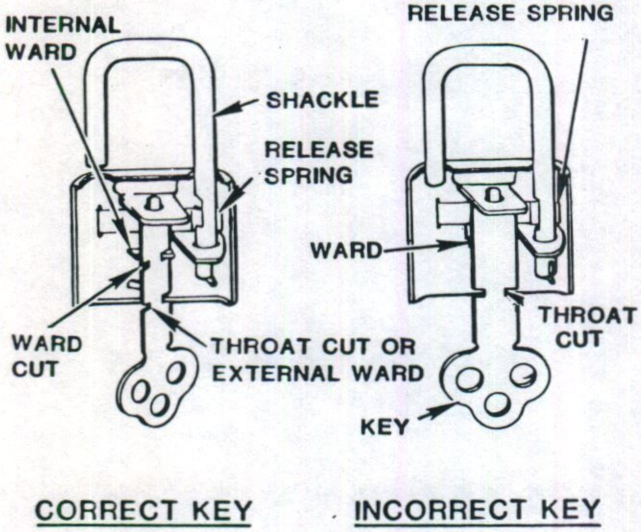

Figure 14-1. Warded Lock

Warded locks were once popular as door locks and may still be found in some older hotels and residences. Currently, most warded locks manufactured in the United States are padlocks. Both the padlock and the warded door lock are easily picked. In addition, warded skeleton keys (passkeys) are easy to fabricate and are readily available through commercial sources.

Since the warded lock cannot be keyed with a master key as such, it has limited usefulness and versatility. Nor can the warded lock be recoded for a different key; therefore, if a warded lock is compromised, it must be removed from service.

Wafer Locks

Wafer locks were invented in the United States in the late 1800's. Their low manufacturing cost and mass production capability have led to the widespread use of wafer locks for many different applications, e.g., locks for luggage, showcases, desks, and cabinets, some types of padlocks, switch locks, etc. Wafer locks offer better resistance to picking and impressioning than do present-day warded locks. Master keying of wafer locks is possible; however, only 200 to 500 usable combinations are available. These locks can be rekeyed but, due to their low cost, replacement of the lock is more practical than rekeying.

The wafer lock, shown in Figure 14-2, consists of a cylinder plug or core which is held in place by a stack of spring-loaded, flat metal wafers. Each wafer has a rectangular cutout in the center through which the key passes; the ends of the wafers protrude from the cylinder plug into the cylinder housing. When the proper key is inserted into the lock, the wafers are aligned so that none protrude from the cylinder plug, allowing the plug to rotate within the cylinder housing.

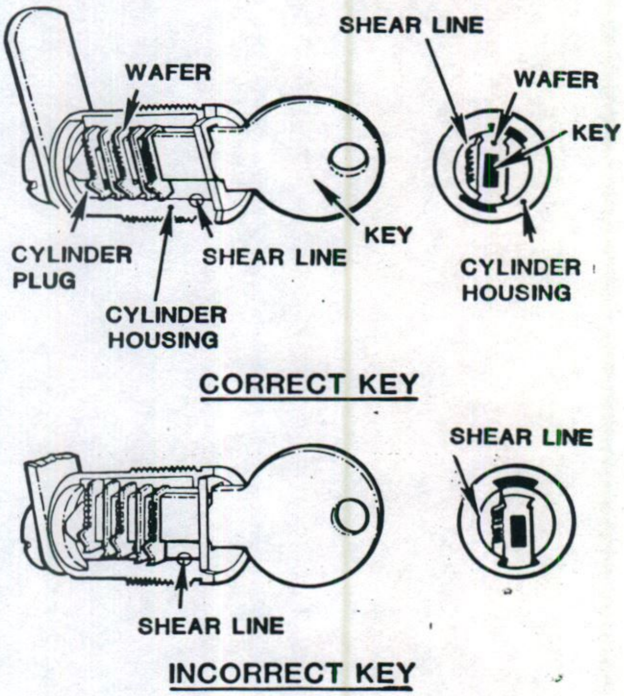

Figure 14-2. Wafer Lock

Pin-Tumbler Locks

Pin-tumbler locks, patented by Linus Yale in the late 1800's, offer more security than warded locks or wafer locks. However, in their standard form, pin-tumbler locks are also vulnerable to easy picking and impressioning.

The standard pin-tumbler lock, shown in Figure 14-3, consists of a cylinder case which contains a cylinder plug or core. The lock case houses several small, spring-loaded pins placed in line and extending into the key-way. The top (or driver) pins are forced down by the springs into the plug to prohibit plug rotation. The coneshaped end of each bottom (or key) pin rests against the inserted key; if the key is properly cut, it raises the break between the top and bottom pins so that each break is even with the outer surface of the cylinder plug (shear line). When the pins are thus aligned, the cylinder plug can be rotated.

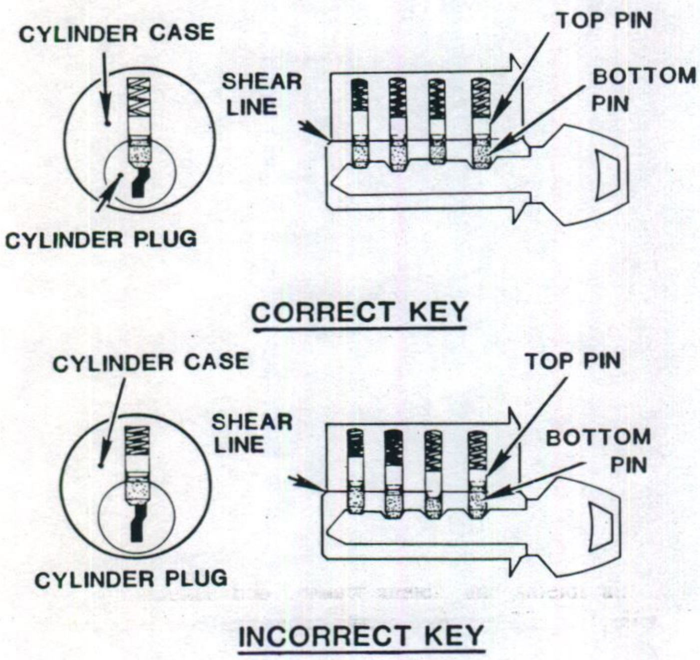

Figure 14-3. Standard Pin-Tumbler Lock

Pin-tumbler locks are usually manufactured to high tolerance specifications and offer a number of different possible key codes. They can easily be master keyed for tens of thousands of possible combinations. Very complex master-keying systems can be developed using pin-tumbler locks. The pin-tumbler lock is widely used in the United States in padlocks and door locks and for special applications.

Lever Locks

Lever locks originated in Europe in the late 1700's and are still currently in wide use. In the United States, their principal application is in locks for post office letter boxes, pay telephone coin boxes, and safe deposit boxes and in several types of padlocks. Lever locks can provide medium to high resistance to picking.

Different key combinations for lever locks can be obtained by either changing the position of the levers or by replacing the levers. The lever lock is usually limited to a simple master-keying system.

The operation of a typical lever lock is illustrated in Figure 14-4. Several flat metal levers (or tumblers) are attached by a pin to a common point at one end of the lock in such a way that the levers are free to swing slightly and are positioned so that rotation of the key exerts a force that retracts the bolt. Each of the levers has a rectangular gate cut in the free end. The bolt has a protruding fence which rests against the free ends of the levers to prevent retraction of the bolt when it is locked. When the correct key is inserted and rotated, the bitting or key cuts on the key elevate the free ends of the levers so that the gates are aligned, thus permitting the fence on the bolt to enter the gates. After the fence enters the gates, bolt retraction is completed by further key rotation.

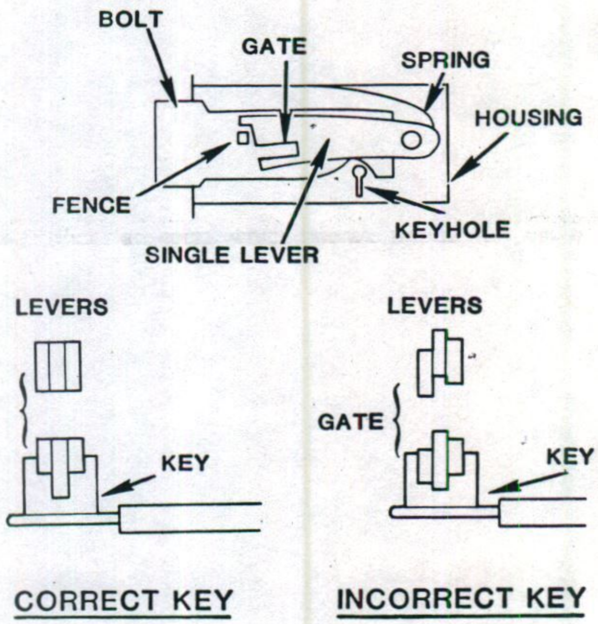

Figure 14-4. Lever Lock Operation

Large lever locks are commonly used in prison security applications. These larger locks are resistant to picking, primarily due to their massiveness and the strength of the springs on the levers. A further refinement incorporated into some lever locks requires that the key be turned several times in order for the bolt to be completely retracted. In this case, the lock must be picked once for each required key rotation.

Another feature incorporated into some lever locks to increase resistance to picking is the use of serrations. If the fence prematurely contacts the end of the lever tumblers, as it must do if an attempt is made to pick the lock, the serrations on the levers engage similar serrations on the fence and prevent the movement necessary to align the fence and gates.

Key Lock Options and Variations

Master Keying — Master keying is an option in the keying of a set of similar keyed locks to open with a common key. Only the pin-tumbler mechanism is designed for complex master keying. For this reason, the pin-tumbler lock is very popular. The pin-tumbler lock can be master keyed by the splitting of the bottom pin or pins into two or more segments (master wafers), thereby allowing more than one shear line to become available. This principle is illustrated in Figure 14-5.

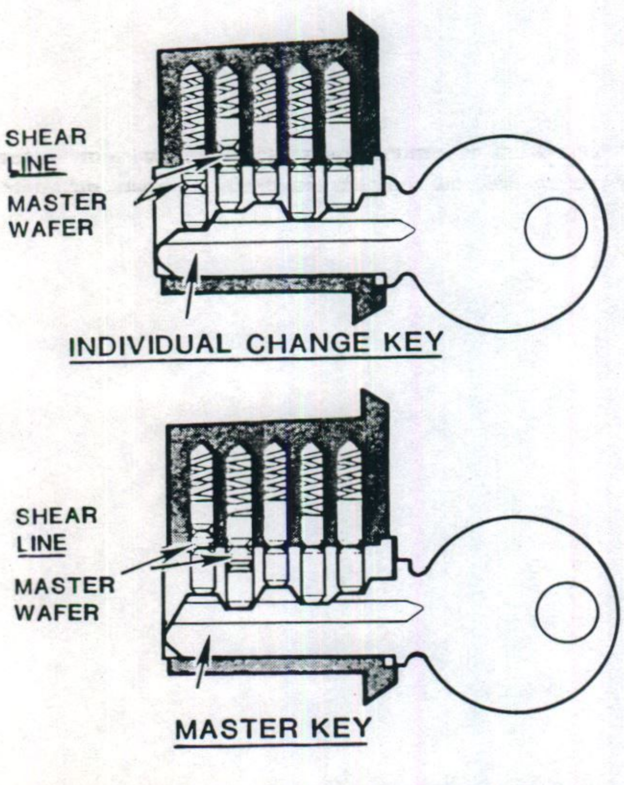

Figure 14-5. Example of Pin Splitting for Master Keying

As the quantity of master-key levels increases, i.e., master, grand master, etc. (see Figure 14-6), so does the number of splits required. The probability that a lock can be compromised by picking or impressioning to a shear line increases sharply with increasing levels of master keying.

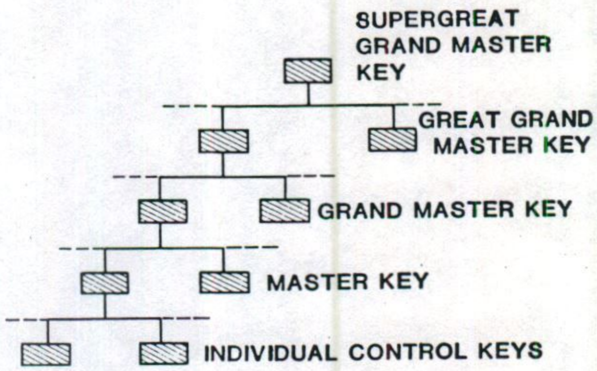

Figure 14-6. Master Keying System

The picking vulnerabilities inherent in conventional master keying have created a widespread need for more sophisticated key cylinders. Several cylinders are available which provide greater security than those previously discussed. An example of such a sophisticated cylinder is the bicentric cylinder (see Figure 14-7), which is constructed of two separate rotating plugs. One form of this lock requires two keys for entry. A second option allows entry through the use of either a standard change key or a master key. No degradation occurs within the first level of master keying.

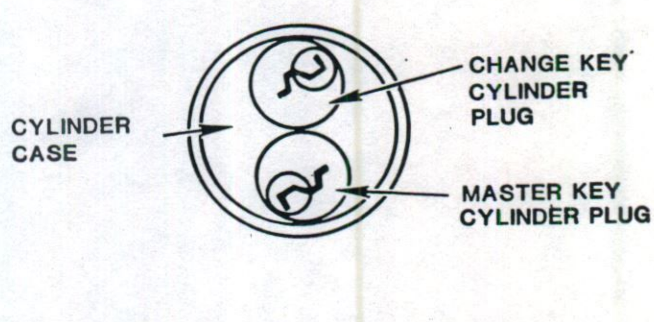

Figure 14-7. Bicentric Cylinder

Another method of first-level master keying is accomplished through the use of a master ring formed around the regular plug. The addition of this ring results in the creation of two shear lines (see Figure 14-8).

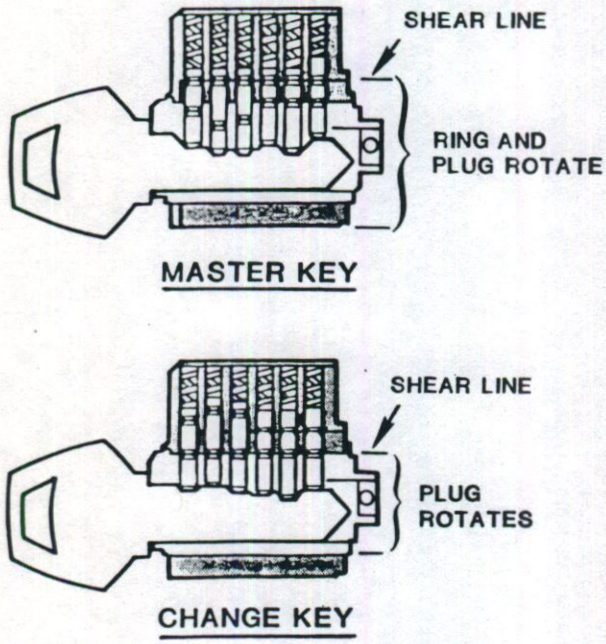

Figure 14-8. Master Ring

A fourth method of master keying provides for keying totally within the key rather than within the cylinder. Since master keying is not accomplished in the cylinder, the total system cannot be defeated by simply disassembling the cylinder in order to determine the key combination. In this system, the key contains all the valic master-key impressions necessary for entry as well as false impressions. An example of such a master key is shown in Figure 14-9. This key cannot be duplicated on standard duplicating machines.

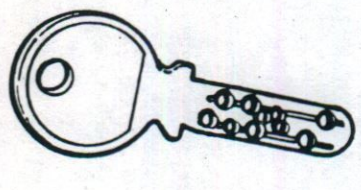

Figure 14-9. Self-Contained Master-Keying Key

Keying Alike — An alternative to master keying is keying alike. Keying alike is the identical keying of one key to several different locks by the use of identical pins for each lock. Although this method of keying does not generate the multiple shear line vulnerability of master keying, it does allow each keyholder to have access to more than one lock.

Keyways — Keyways are keyholes designed using wards or obstacles which increase the master-keying capability of a locking system. Examples of different keyway cross sections are shown in Figure 14-10. The term "restricted keyway" refers to the option offered by some manufacturers in which a particular keyway cross section is exclusively assigned to a customer and blank keys with that cross section are sold, only as authorized, to that customer alone. Restricted keyways are often used to restrict entry in a given keyed section of a total master-keyed facility.

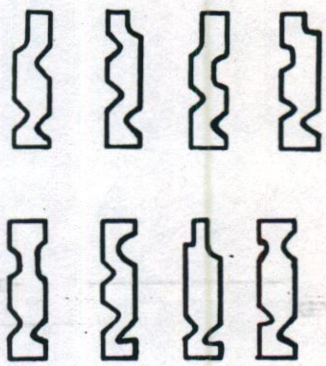

Figure 14-10. Keyway Cross Sections

Pin and Lever Variations — A number of features or principles have been used to improve the standard key lock design. For example, variations in the standard straight cylindrical pins of the pin-tumbler lock can increase its resistance to picking; lever locks which employ false gates are less susceptible to picking (Figure 14-11). Such variations are used to confuse individuals attempting surreptitious entry and also to increase the amount of time required to defeat the lock.

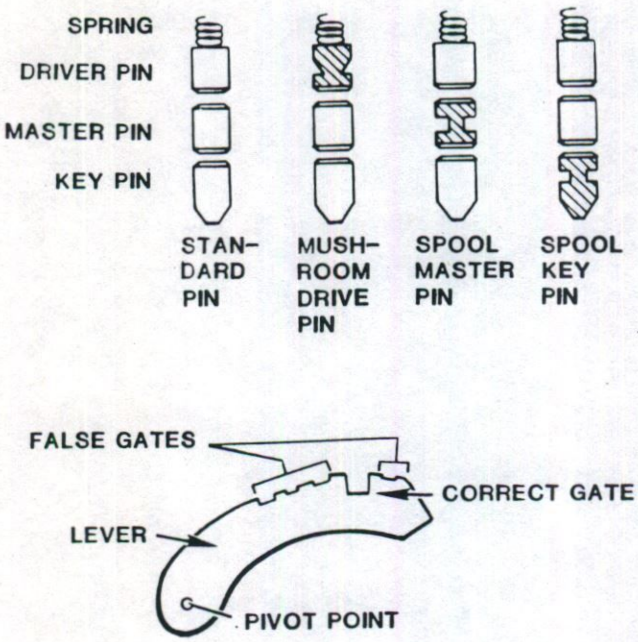

Figure 14-11. Pin and Lever Variations

Tubular Locks — The tubular lock, shown in Figure 14-12, uses a round key to depress the concentric pattern of pin tumblers which project toward the face of the lock. The tubular lock has been used extensively in the past. Recently, however, acceptance of this lock for sensitive applications has decreased; this is primarily due to the appearance on the market of pick tools tailored especially to this type of lock.

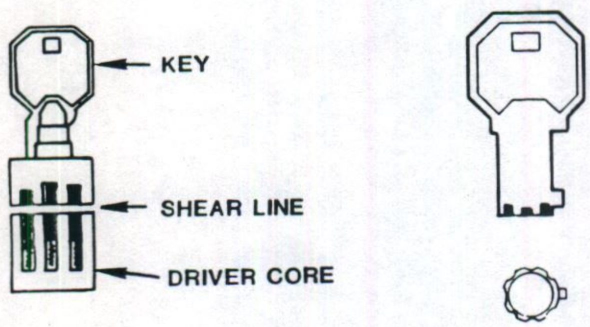

Figure 14-12. Tubular Locks

Dual Pin Action — Some pin-tumbler lock cylinders require that the pins, in addition to being elevated to the shear line, also be rotated to a proper orientation, which will increase pick and impressioning resistance. This dual pin action is accomplished by the use of key cuts that have varied angles and depths. A comparison between a standard one-motion, pin-tumbler lock and key and a two-motion system is shown in Figure 14-13.

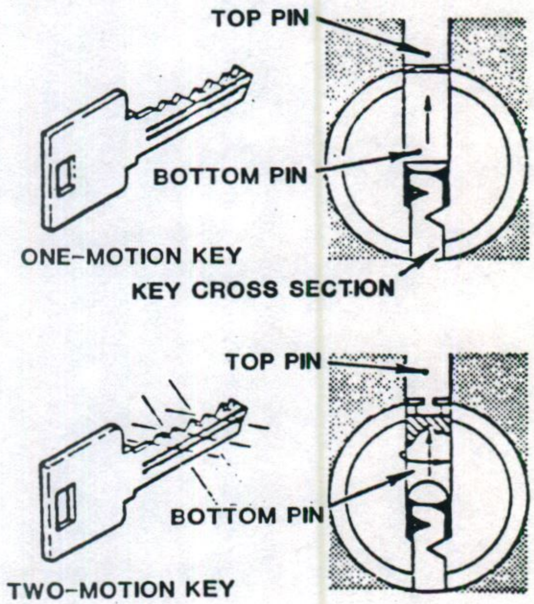

Figure 14-13. Standard and Dual Pin-Tumbler Keys and Cylinders

Multirow Radial Pin-Tumbler Locks — Another unique method of keying the pin-tumbler lock entails the use of pins arranged radially in the cylinder so that the pins rest on more than one surface of the key, as shown in Figure 14-14. This type of keying produces a smooth profile key rather than the traditional sawtooth key. The key contains dimples located on the sides of the key to position the pins to their proper depth. Because more key surface contact is available, the number of pins contained within the cylinder can be increased and therefore can increase pick resistance.

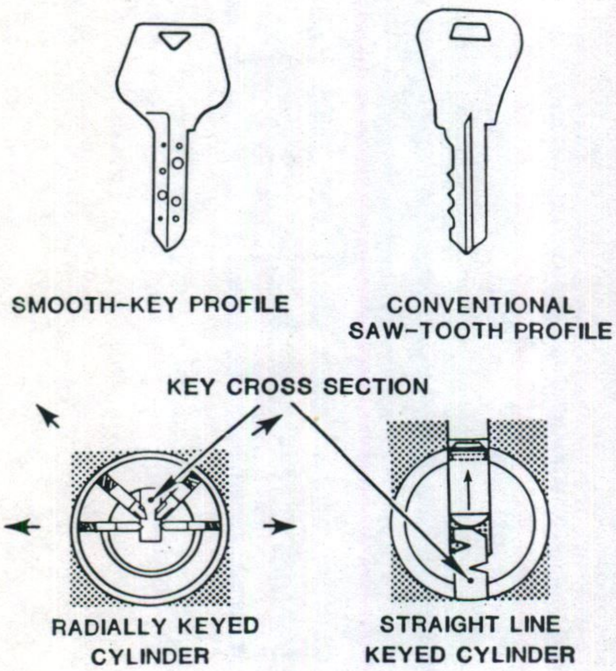

Figure 14-14. Standard and Multirow Radial Keys and Cylinders

Rotating Tumbler Disk Locks — Rotating tumbler disk locks are highly pick-resistant locks which operate using a specially cut cylindrical key which rotates individual disks in the cylinder to different turn angles. When the key is inserted and rotated, the disk notches align, allowing a locking bar to drop into position. This action frees the otherwise constrained plug which contains the disks and allows the plug to rotate. An example of the tumbler disk lock is shown in Figure 14-15.

Removable Core Locks — The cost of lock hardware becomes a predominant factor in lock selection when several hundreds or thousands of padlocks and door locks must be quickly replaced or rekeyed. Removable core locks are often used by large facilities because they can be exchanged expediently. During the exchange procedure, the entire key mechanism is removed and replaced with a differently keyed core. This operation requires only seconds to perform. Removable cores can be retained within the lock in several different ways, as shown in Figure 14-16.

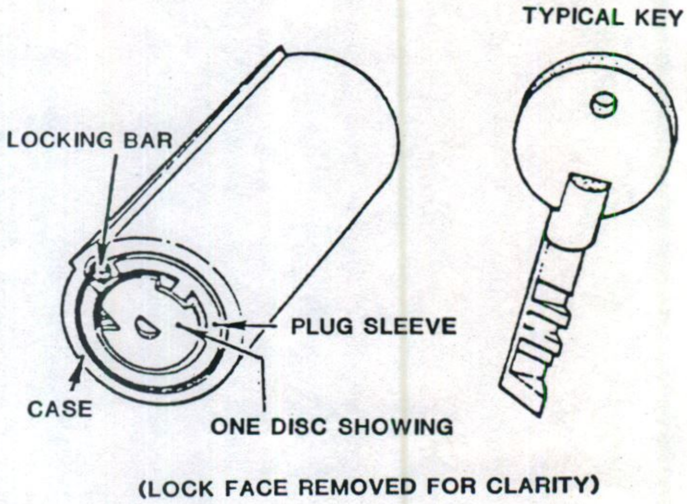

Figure 14-15. Rotating Tumbler Disk Lock

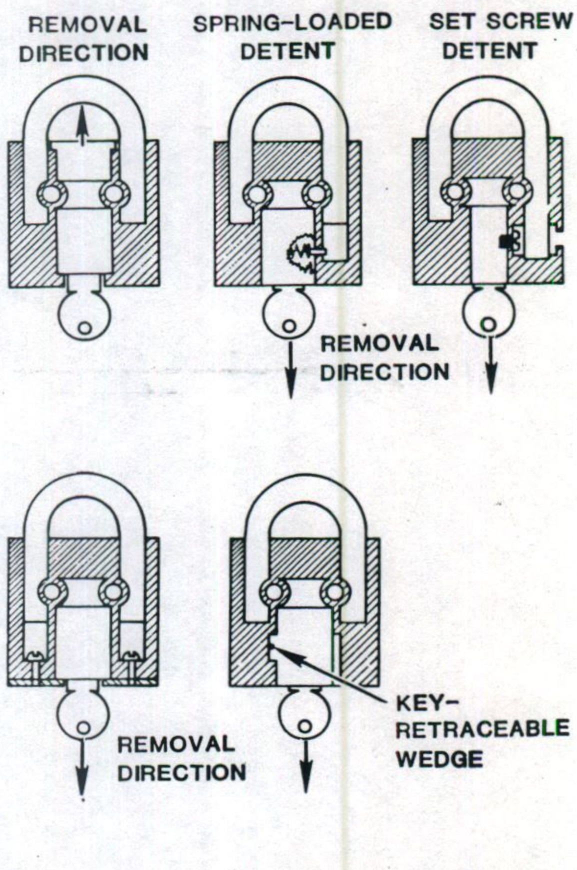

Figure 14-16. Removable Core Key Mechanisms

Keyless Locks

A keyless lock is a device which is operated by the use of a code to gain access. The category of keyless locks includes traditional combination locks and mechanical or electronic coded locks.

Traditional Combination Locks

The principal advantage of combination locks is that they can be highly resistant to most forms of surreptitious attack. A combination lock may have as many as 1 million possible combinations, which effectively eliminates the possibility of an individual opening the lock by dialing all possible combinations. In addition, most combination locks, in general, do not provide access holes for "picking." However, a unique code combination must be selected and protected for the combination lock.

Combination locks are usually incorporated into padlocks or door locks. The principles of operation are the same for the majority of these locks. Combination padlocks range in complexity from the simple locker-room variety padlock to the highly developed changeable combination padlock. Frequently, the bolt of the combination door lock is not directly used to secure the door; the lock bolt is used to secure a larger mechanism consisting of locking bolts, which, in turn, secure the door to its frame.

A combination lock contains a dial which is usually divided into sections marked with numbers. The dial may be the only portion of the lock that is visible. The combination dial transmits its motion to code tumblers or wheels located within the locking cylinder. Combination locks typically have three or four tumblers. There are as many tumblers as there are individual numbers in the combination. For example, the combination 11-34-46 has three distinct numbers and, correspondingly, the combination lock which used this combination would have three tumblers. A drive cam is fixed directly to the combination dial spindle. When the dial is moved, the drive cam also moves. Each tumbler has a gate located on its circumference and a drive pin which sits on its flat surface. The tumblers rotate around a spindle. Rotation of the tumblers is controlled by contact between the tumbler drive pins. The tumbler farthest from the drive cam aligns with the first combination number. When the correct combination is dialed, the gates of all the tumblers are aligned so that the fence moves into the gates, allowing the bolt to be retracted. These features of the combination lock are shown in Figure 14-17.

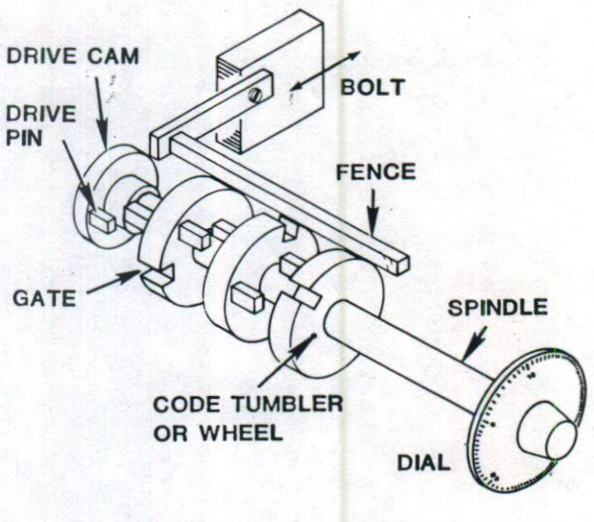

Figure 14-17. Combination Lock Schematic

Several methods can be used to change the combination of a lock. The most common method of changing a combination is accomplished through the use of a key which is inserted into the rear of the mechanism. Each tumbler of the lock must be recoded by changing the angular position of the gate relative to the drive pin on the tumbler. This is a simple task which requires only a few minutes time.

Key-changeable locks are operationally convenient but are also vulnerable to compromise when they are unlocked and the key access hole is accessible to unauthorized persons. Modern combination locks are highly resistant to most forms of surreptitious attack because normal operation does not require direct access to the lock mechanism as does, for example, the locking mechanism of a key lock.

Prior to the 1950's, many combination locks could be opened by a person who had no knowledge of the combination by simply listening to the sound of the tumbler movements and by sensing the drag on the tumblers which resulted from the fence resting on the edge of the tumblers. In manipulation-resistant combination locks, the fence does not rest on the tumblers. Manipulative methods of entry can still be used to defeat some locks today. Further refinements used in some combination locks include nylon tumblers to resist decoding with X-rays and sound baffles.

Mechanical Coded Locks

The operation of a mechanical lock is controlled by push buttons or dials which are connected to a mechanical coding device. Proper operation of the pushbuttons or dials allows the withdrawal of a latch or bolt. The schematic in Figure 14-18 shows a typical mechanical lock. The resistance to picking of mechanical locks is probably better than that of standard pin-tumbler locks but not as good as several of the available better quality key locks.

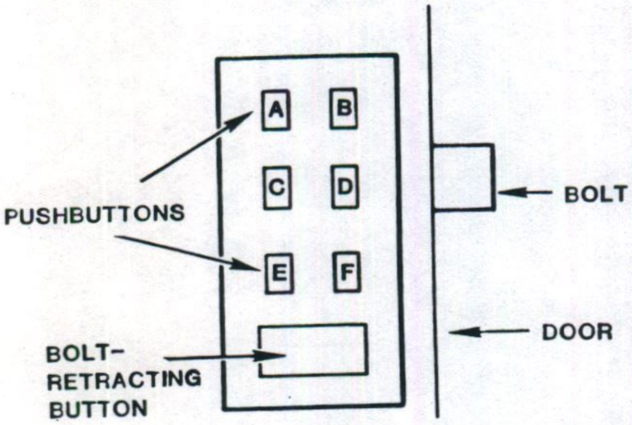

Figure 14-18. Mechanical Lock Schematic

Electronic Coded Locks

The basic elements of an electronic lock are coded panels or credential readers, logic systems, and solenoid-actuated bolts or strikes. These elements are used in various arrangements and combinations to provide a range of security levels and costs. Chapter 2 of the *Entry-Control Systems Handbook* describes the various credential readers available.[2]

Electromagnetic Latches

Electromagnetic doors do not have bolt hardware. These latches consist of an armature (strike plate) which is surface-mounted to the door and an electromagnet installed in the door frame. The two-piece latch, which has no moving parts, magnetically bonds the door and frame together when energized and releases the door when deenergized. Some devices are advertised as capable of withstanding 3,000 pounds of force.

Bolt/Strike Mechanisms

Bolt mechanisms, which are used to join barriers together, are divided into two general categories according to the type of power used to move the bolt: electrical or mechanical. Some locking devices are designed to use either type of operating power.

The operation of electric bolts is controlled by either application or removal of electrical power to a solenoid- or motor-operated bolt. Another method of electrical door control employs a solenoid-operated strike. The bolt or strike operates in one of two modes: fail-secure unlocked when energized) or fail-safe (locked when energized). The fail-safe device is usually preferred for reasons of safety but degrades security since, in the event of a power failure, it automatically unlocks. Auxiliary power supplies are usually required.

Mechanical bolts are constrained in their projected positions either by a spring or by interference from a solid obstacle. Both types of constraints are used in padlocks and door locks which are activated either by a key or combination mechanism. The bolt or latch function is usually designated as a spring-loaded latch, a deadlocking latch, or a deadbolt.

A spring-loaded latch is a latch which is automatically projected by spring action (see Figure 14-19).

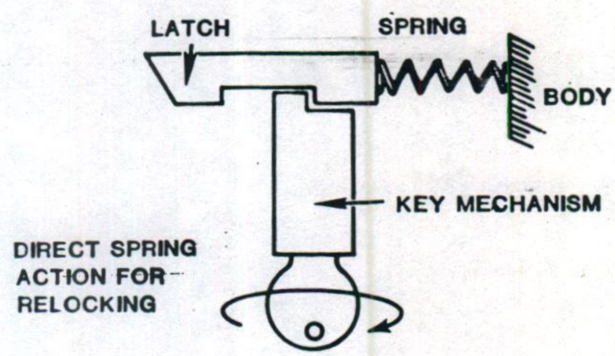

Figure 14-19. Spring-Loaded Latch

Spring latches are not positively coupled to their key/combination mechanism and, therefore, can be easily defeated. The use of a deadlatch or secondary bolt in conjunction with a spring latch is found most often in door locks. The deadlatch is depressed as the door is shut, placing an obstacle in the path of the spring latch which restricts its movement (see Figure 14-20).

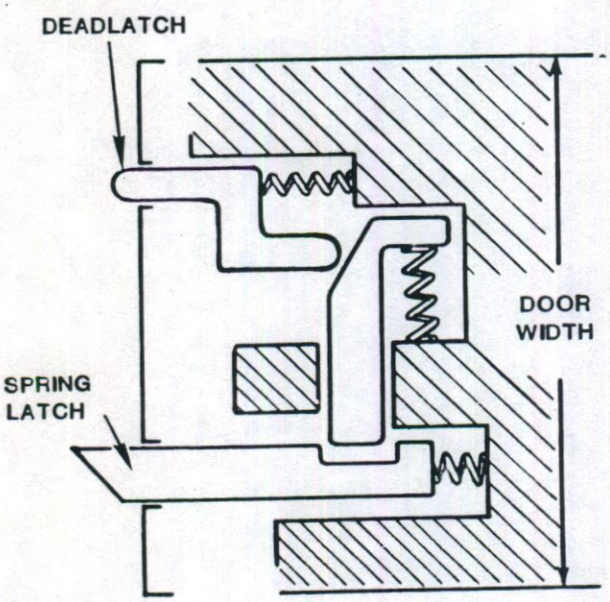

Figure 14-20. Dead-Locking Latch

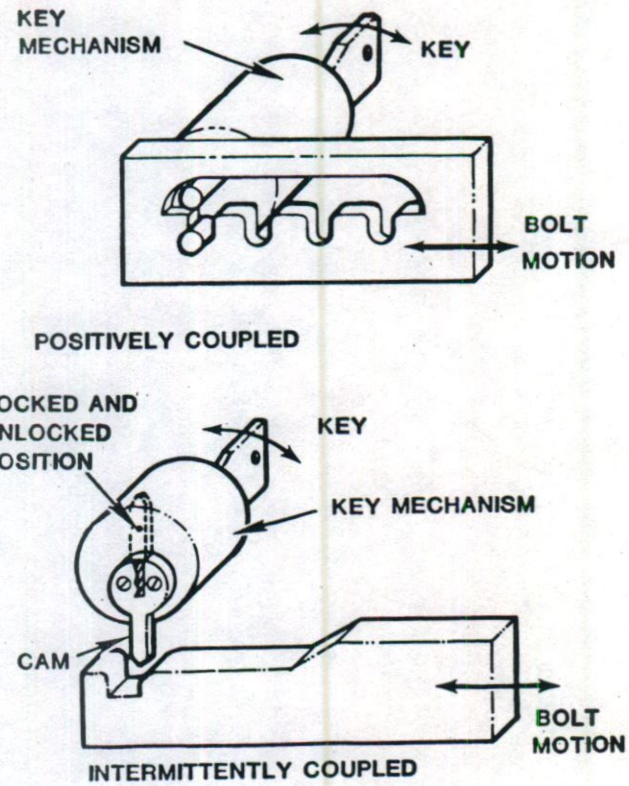

Figure 14-21. Deadbolt, Key-Operated

A deadbolt has no spring action and becomes locked against end pressure when it is fully projected. Deadbolts are either positively coupled or intermittently coupled to the key mechanism (Figure 14-21). Those key locks which are positively coupled require correct key operation for unlocking. Intermittently coupled key locks can often be defeated by bolt manipulation without rotation (operation) of the mechanism.

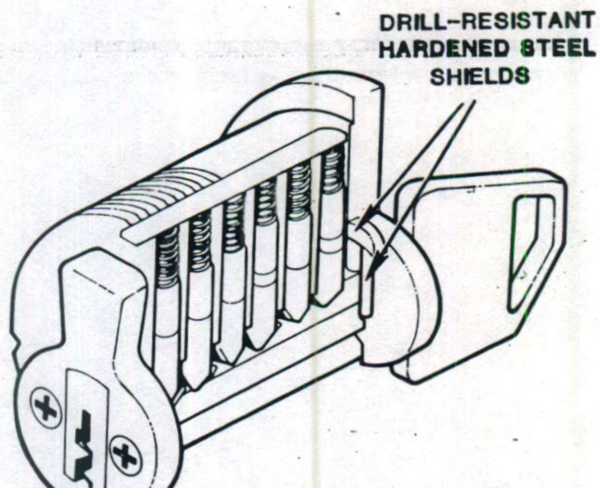

Figure 14-22. Hardened Shields

Hardened Barriers

Few locking devices contain hardened barriers to deter the use of force. Key cylinders may contain hardened shields (plates or pins) to resist drilling (see Figure 14-22). Often padlock bodies and shackles are hardened; shackle exposure ranges from exposed to totally concealed (see Figure 14-23).

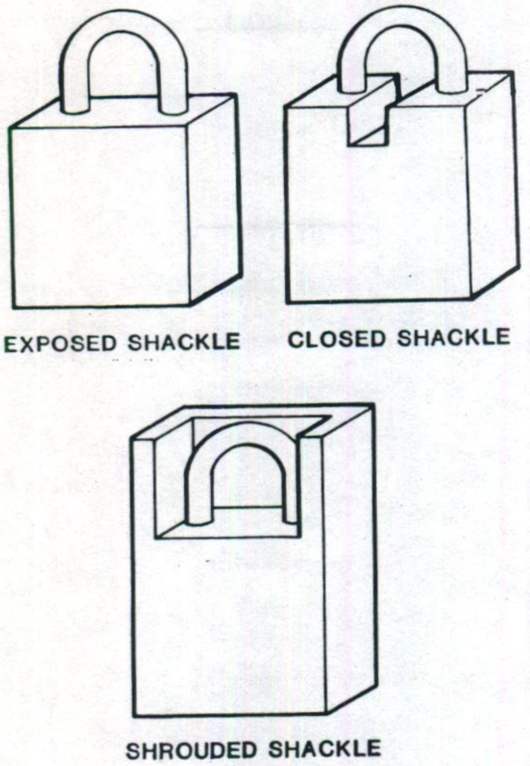

Figure 14-23. Shackle Exposure

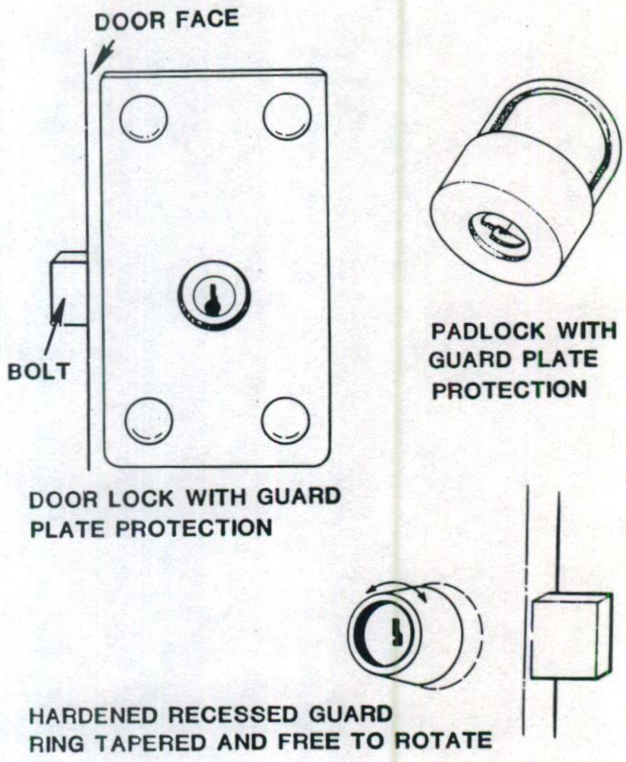

Figure 14-24. Hardened Guard Plates and Rings

Since the amount of key rotation for padlocks is smaller than the key rotation for door locks, the padlock body can often be extended into the key-turning area, providing guard plate protection (see Figure 14-24). Some locks contain hardened guard plates and/or cylinder guard rings. Generally, the more removed the lock is from the face of the door the more protected is its position. This protection can also be provided by the use of a guard plate which covers as much of the cylinder as possible while still permitting the key to be turned.

Hardened guard rings must be recessed and have sufficient taper and rotation to withstand forcible defeat, as shown in Figure 14-24.

Padlock and Hasp

A padlock is a unique removable lock. The key padlock consists of a body, shackle, bolt or latch, and key mechanism or key cylinder. (All four of these parts are usually present in the padlock, although they may or may not be disassembled as individual parts.) In most applications, the entire padlock is exposed and is therefore subject to methods of defeat to which other locks are not normally subjected. A hasp is usually used in combination with a padlock.

A hasp is a metal fastener with a minimum of two sections. The sections are attached to a movable and a fixed barrier or to two movable barriers, respectively. When the barrier(s) is closed, the two sections of the hasp are positioned together in such a manner that the shackle of the padlock can be inserted through both to fasten the two sections together. Only a few varieties of hasps are commercially available and most are not comparable in quality (in terms of resistance to forcible attack) to the high-security padlocks which might be used in conjunction with them.

Hasp designs usually vary considerably due to different mounting requirements. Hasps can be either mounted with nonremovable bolts or welded directly to the door or frame. Not all padlocks and hasps can be combined together, but many are universally adaptable. Figure 14-25 illustrates a typical padlock/hasp configuration.

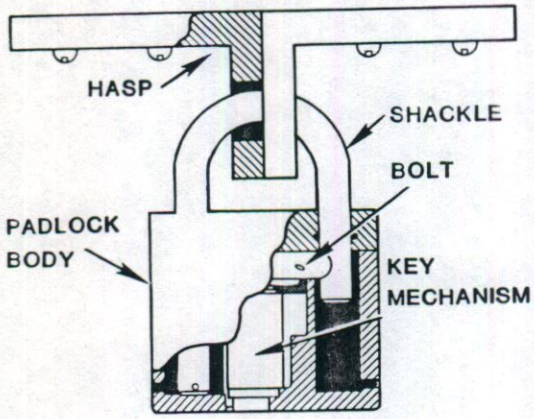

Figure 14-25. Cutaway View of Padlock and Hasp

Door Locks

A number of key door lock designs have evolved over the years. The most popular styles of locksets can be grouped into four types: mortise, rim, auxiliary, and key-in-knob.

The bolt mechanism, key cylinder, and, often, the safety and convenience linkages are housed in a lockset. In many cases, the key cylinders can be interchanged with other manufacturers' locksets, e.g., a Sargent key cylinder may be used to operate a Yale bolt mechanism.

The mortise lockset is placed into a rectangular hole which is cut in the edge of the door or, in some cases, the door frame. In mortise locks used in the United States, the key cylinders are screwed into the lockset and generally are secured from rotation with one set screw. A cam is attached to the rear of the cylinder plug. This cam rotates when the plug rotates. At some point during rotation (intermittently), the cam couples with the bolt, which slides into either the locked or unlocked position. Figure 14-26 compares the U.S. and European style mortise locks. The European cylinders differ noticeably from U.S. cylinders and are not interchangeable with U.S. hardware. In addition, European locks are not vulnerable to many attack methods which are successful against U.S. locks.

The rim lockset is fixed to the inner door face of the door and the rim cylnder protrudes through the outer door face. The rim cylinder is usually attached with two screws to the housing which contains the bolt mechanism. As the key is rotated in the lock, the cylinder plug and an

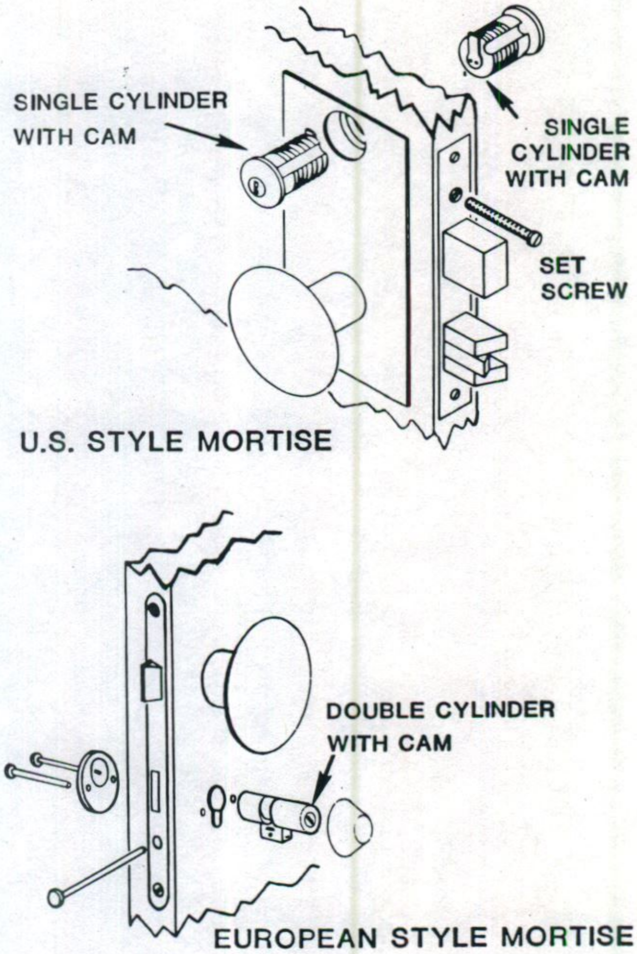

Figure 14-26. Mortise Lock Styles

attached tail piece also rotate. The tail piece is either positively coupled or intermittently coupled to the bolt, which slides into either the extended or retracted position (see Figure 14-27).

Auxiliary locks are often used as add-on locks which become the primary locking device. These locks are usually inserted into a hole which is cut through the door face. For the most part, auxiliary key cylinders are not standardized and therefore are usually not interchangeable with other manufacturers' hardware. Some key cylinders are attached with hardened screws similar to those used for rim cylinders, while others are secured in a manner similar to mortise cylinders.

The key cylinder often protrudes from the door with a cylindrical guard ring for protection (see Figure 14-28).

The key-in-knob lock is very popular throughout the United States. Its design is somewhat different than the design of the locks previously described. The primary

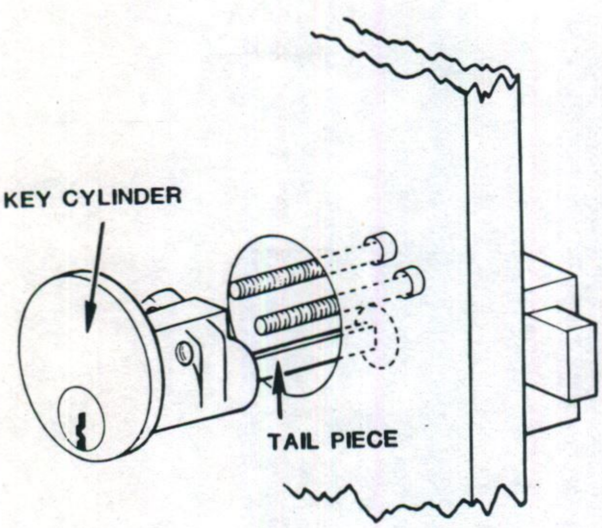

Figure 14-27. Rim Lock Styles

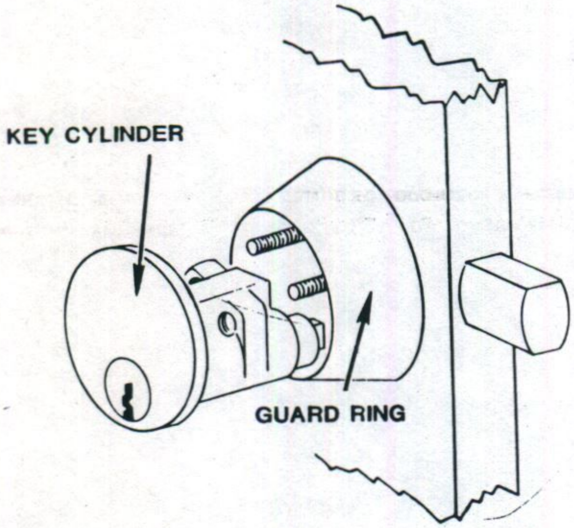

Figure 14-28. Auxiliary Lock Style

difference is that the entire lock control mechanism is contained within the door knob (Figure 14-29). The key-in-knob lockset is generally more vulnerable to forcible attack than are other key locks; additional hardware increases its protection only slightly.

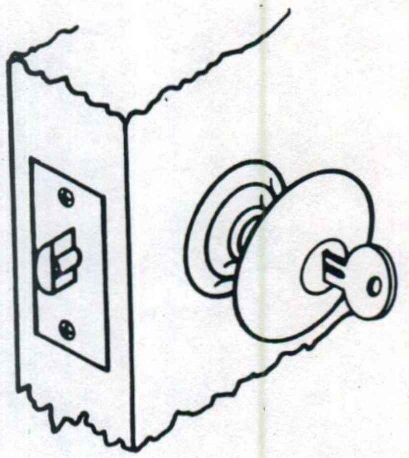

Figure 14-29. Key-in-Knob Lock Style

KEY LOCK DEFEAT METHODS

The methods used to defeat locks can be divided into two classes: (1) surreptitious defeat and (2) forcible defeat. Surreptitious defeat is defined as the opening (entry) of a lock such a manner that inspection of the lock will most likely fail to detect evidence of tampering. The inspection, as referred to here, consists of a careful visual field examination of the lock by a conscientious security inspector and does not include a detailed examination of the disassembled lock. A forcible defeat is defined as the opening of a lock in such a manner that careful visual field examination of the lock would most likely detect evidence of tampering.

A wide range of key lock defeat methods is described in the following paragraphs. These defeat methods include:

Surreptitious Defeat Methods:

- Picking
- Decoding
- Impressioning
- Rapping
- Bolt Manipulation
- Core removal
- Wedge separation
- Pulling
- Grinding
- Drilling
- Thermal defeat

Forcible Defeat Methods:

- Core removal
- Wedge separation
- Pulling
- Grinding
- Drilling
- Thermal defeat
- Sawing
- Cryogenic cooling
- Boltcutters
- Explosives

All key locks are susceptible to picking, decoding, and impressioning but these methods of defeat usually require significant time and skill. On the other hand, bolt manipulation requires only a working knowledge of the locking device and can usually be accomplished in much less time. Most U.S. locks, if not adequately protected, are vulnerable to manipulation defeat in seconds.

Times for forcible defeats such as thermal or explosive attacks generally range from seconds to several minutes, depending upon the tools used and the lock protection. In most cases, unrepairable damage results.

Picking

Lock picking is a method of surreptitious entry which defeats a lock by attacking the key mechanism.

All key locks are susceptible to picking. The time required varies depending on the lock and the skill of the intruder. The time to defeat a key lock by means of picking, even for a person skilled in picking techniques, ranges from seconds for a simple lock to tens of minutes for a more difficult lock.

Decoding

Lock decoding (or reading) is another surreptitious defeat method which attacks the key mechanism through the use of specialized tools. Potentially, all locks are vulnerable to decoding. A pick-like process is used to measure the proper positions of the various pins, disks, or levers that will permit the lock to open. This information is then used to fabricate a new key.

Tubular lock decoding can be accomplished in only a few minutes (or in some cases a few seconds) even by a nonprofessional.

Impressioning

Impressioning is a technique used to produce a key capable of unlocking a lock. Impressioning can be accomplished either by key access or by cylinder access. Both methods produce the same results. If a key is directly accessible, an impression casting an be used to duplicate a key. If only key cylinder access is possible, a key blank can be marked and filed to fit. The time needed to do the actual marking, which must be performed on site, is of fairly short duration. The key blank can be filed at another location. The intruder needs to return to the lock only when it is necessary to remark the key; however, remarking usually necessitates several return trips.

Rapping

Rapping refers to a method of transferring a mechanical impulse to the lock. Rapping causes the bolt to momentarily disengage, allowing the lock to open. Only a few locks with spring-loaded latches or bolts can be opened by rapping.

Bolt Manipulation

Bolt manipulation is an attack method used in defeating the bolt mechanism of a lock. Shimming is one method of bolt manipulation. Shimming attacks the bolt mechanism within a padlock or door lock and can only be accomplished if the bolt is not a positively coupled deadbolt.

Bypassing is another method of bolt manipulation aimed at defeating the bolt mechanism by bypassing the key cylinder and retracting the bolt. This procedure, if done correctly, takes only seconds.

Core Removal

Almost all removable core cylinders which are changeable from the keyed direction can be forcibly pulled in less than 2 minutes. This operation usually does not damage the case.

Wedge Separation

Wedge separation is a method used to forcibly defeat padlocks. The shackle locking bolt usually fails in shear. After entry has been accomplished, the intruder might be able to eliminate most of the evidence by forcing the lock back together.

Pulling

Pulling consists of the removal of a mortise or rim cylinder from a door lock. Pulling is accomplished by simply pinching or wedging the cylinder and then pulling it out of the door encasement.

Grinding

A lever lock with a cylindrical plug can usually be defeated by grinding through the cylindrical housing face which secures the key cylinder in the lock. This allows the insides of the lock to be quickly removed.

Drilling

Drilling any one of several areas on a lock face can defeat most locks in less than 2 minutes by bypassing the key mechanism. The drilled hole itself either defeats the mechanism or provides access for manipulation defeat.

Thermal Defeat

Several key mechanisms in both padlock and door lock designs use materials with low melting points. Frequently, a torch can be used to melt the materials. Often, damage to the lock is not noticeable on the exterior and will pass casual inspection. Thermal tools can also be used to cut or melt a lock in seconds.

Sawing

Even though padlock shackles are often heat treated in order to provide extreme hardness, the exposed shackles can be defeated by sawing. Door bolts can also be cut if they are sufficiently exposed. A saw attack against the bolt is only effective if the bolt is composed of soft material and if it does not have freely rotating, hardened pins.

Cryogenic Cooling

Cryogenic coolants can be used to embrittle padlock materials so that only one or two blows are needed to break the padlock.

Boltcutters

With few exceptions, most exposed padlock shackles can be defeated by the use of manual boltcutters.

Explosives

If noise is not of concern to the intruder, an explosive can provide a quick and easy attack method against door locks and padlocks.

REFERENCES

1. J. V. Williams, *Lock Handbook (U)* SAND78-0500 (Albuquerque: Sandia Laboratories, June 1979) (CNSI). More information is available in SAND78-0500 Revised December 1980.

2. *Entry-Control Systems Handbook*, SAND77-1033 (Albuquerque: Sandia National Laboratories, revised September 1980).

CHAPTER 15

PENETRATION RATES AND DATA BASE

INTRODUCTION

The purpose of this chapter is to present rate graphs, tables, and a barrier data base that will

1. Permit credible penetration time estimates for single or multiple barriers and/or attack methods not specifically addressed by the data base alone. These estimates could be made by using the data base together with standard times and rates to accomplish various tasks,
2. Provide a central source of barrier penetration times for physical protection systems effectiveness evaluations, and
3. Aid designers in the selection of barrier improvements and as a stimulus for new designs.

The information contained in the rate graphs, tables, and the data base may also aid in the development of a total unopposed scenario or adversary task times by combining the individual barrier penetration times with the other required scenario tasks, such as traveling time between barriers (walking, running, crawling, climbing, metal cutting, digging rates, etc.). Total adversary task times can be considered along with the other physical protection system elements (detection and guard response) in making effectiveness evaluations. Examples of penetration time for an individual barrier and for a total scenario are also presented.

The rate information has been developed from data points measured in actual tests. Penetration times have been developed by three methods:

1. Literature Search. Where considered pertinent, data developed by other agencies are included in the barrier data base.
2. Prototype Testing. Penetration times of test barriers by various attack modes have been measured.
3. Estimates. This method establishes penetration times based on extrapolated or interpolated data from similar barrier tests and standard rates.

Some barriers have received extensive evaluations, some have received only a small amount of evaluation, and some have not yet been evaluated.

PROBABILITY DISTRIBUTION

All task rates in the graphs, tables, and the data base penetration times in this chapter are mean rates. A triangular, symmetrical distribution about the mean rate is assumed for all entries. Maximum and minimum rates are plus and minus 50 percent of the mean rate.

The mean penetration times and probability distributions in the data base tables are not derived from a statistically meaningful number of tests. Many entries are either based upon one test or are estimated values. The estimated values were derived from extrapolated or interpolated test data from tests on similar barriers, the rates graphs, tables, and the collective judgment of the barrier evaluation staff. Estimated values have been included to expedite information required for facility evaluations and to provide a basis for comparison of barrier upgrades and advanced concepts.

The probability distribution of the data is not included in the barrier data base format because it is the same for all entries. Distribution of the penetration times (minimum, mean, and maximum) is considered to be symmetrical and triangular. Triangular distributions were chosen as a base line because of their compatibility with a currently used effectiveness evaluation model, Forcible Entry Safeguards Effectiveness Model (FESEM). However, the difference between a triangular distribution and a normal distribution is so small that either distribution can be used. A pictorial representation of the triangular and normal distributions with the same standard deviation are shown in Figure 15-1.

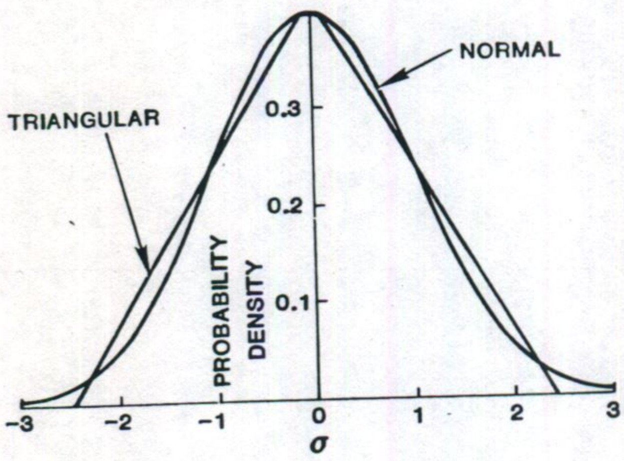

Figure 15-1. Triangular Distribution

The standard deviation (σ) for a triangular distribution can be derived from the equation

$$\sigma = \frac{(\text{Max. time} - \text{Min. time})}{4.9}$$

RATES DEVELOPMENT

Since rates for each task vary, depending upon the physical fitness, size, skill, and luck of the personnel, different penetration times are obtained. Sometimes allowances could be added to the task rates. Judgment must be used in deciding what adverse conditions (time delays) can be expected while penetrating a barrier. For example, burning through a overhead grate may take longer than burning through a vertical grate, even though the burning rate and barrier are identical. This exemplifies the areas of judgment where the following allowances can be made:

1. Rate allowances:
   - Interruptions (by guards, etc.)
   - Set-up and tear-down
   - Tool maintenance
   - Personnel—Rest
   - Delay—Breakage
     Machine stoppage
     Variation in material
   - Fatigue—Difficulty
   - Unfavorable weather
   - Nonproductive time
   - Work area congestion
2. Team or group work allowances:
   - Training
   - Rehearsals
   - Dedication
   - Motivation
3. Human bias allowances:
   - Chance variation (bad/good luck)
   - Unforeseen conditions
   - Skill
   - Effort
   - Stamina

All rates are considered to be performed under ideal, unopposed conditions (no allowances added) by a dedicated group and not by the general population.

PENETRATION TIMES DEVELOPMENT

When it has been considered feasible, actual barriers have been constructed and subjected to various attack modes by special attack teams composed of volunteers of excellent health, physical strength, and stamina. These teams were provided with the necessary tools and equipment, planned their methods, and staged the attacks. Trained observers recorded the actual penetration time for each attack. Tests were evaluated to establish whether the penetration times were "average" (mean), and the times were adjusted accordingly.

Transport time to or from the barrier is not included. Penetration times for individual barriers may require adjustment when considered in context with other barriers and tasks required to complete the entire attack scenario. Minimum and maximum penetration times are presented as a constant minus and plus 50 percent of the mean time. The minimum time represents the shortest time considered possible for penetration of the barrier. The maximum time is considered the longest time thought to be practical for trained adversaries and excludes extraordinary conditions such as tool failure, accidents, etc.

Some penetration times in the data base for two or more barriers similar in construction may appear to be paradoxical, i.e., there may be gross differences in the times required to penetrate. However, the penetration times depend on the tools employed, the methods of penetration, and the attack area of the barrier. (For example, a door may be attacked at the lock, the hinges, or the face.) All entries must be considered individually for their particular penetration scenario. Barrier penetration time is a function of the selected attack mode, which is, in turn, governed by the equipment required. Categories of attack tooling used in this handbook are

1. Hand tools—sledges, axes, boltcutters, wrecking bars, metal cutters,
2. Powered hand tools—hydraulic boltcutters, abrasive saws, electric drills, rotohammers,
3. Thermal cutting tools—oxyacetylene torches, oxy-lances (burn bar),
4. Explosives—bulk, tamped, linear and conical-shaped charges, platter charges, and
5. Trucks used as rams.

USE OF RATE GRAPHS, TABLES, AND DATA-BASE TABLES

The following examples illustrate the use of the rate graphs, tables, and data-base tables to construct barrier penetration times for both individual and combined barrier elements. Example 1 shows the total penetration time for an individual barrier, using the rate graphs alone. Examples 2 and 3 show the penetration times of multiple barriers as developed during a complete adversary scenario. These examples are obtained by the combined use of the rate graphs, for various adversary tasks, and the data-base tables, for specific barriers. Example 3 also illustrates the use of the data base as a source of information for upgrading.

Example 1

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Example 2

A complete adversary scenario may be developed with combined information from the rate graphs and data-base tables. In this example, the intruder is on foot, and the tools employed are hand type and 2 pounds of explosives. A typical facility and the required penetration time in such a scenario are shown in Figure 15-2.

Example 3

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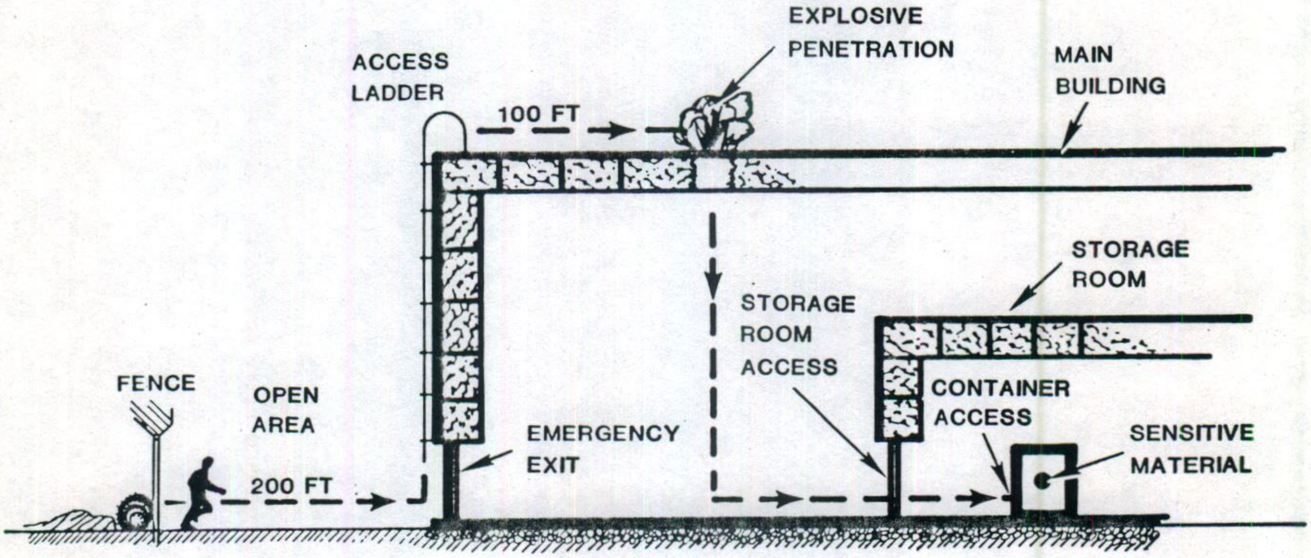

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Figure 15-2. Penetration Time, Example-2 Scenario

RATE GRAPHS

Rate graphs in this section are divided into the following categories and presented in the order listed:

1. Climbing	Figure 15-3
2. Crawling	Figure 15-4
3. Cutting	Figures 15-5 through 15-14
4. Digging	Figures 15-15 through 15-17
5. Explosives	Figures 15-18 through 15-21
6. Running	Figure 15-22
7. Throwing	Figure 15-23
8. Vehicle	Figures 15-24 and 15-25
9. Walking	Figure 15-26

RATE TABLES

Rate tables are presented in the following categories and in the order listed:

Vehicle Access Door	Table 15-1
Mild Steel Wire Mesh Screens	Table 15-2
Steel Panels	Table 15-3
Mild Steel Bar Cutting	Table 15-4
Sheet Metal Ducts	
Cutting	Table 15-5
Crawling	Table 15-6
Climbing	Table 15-7

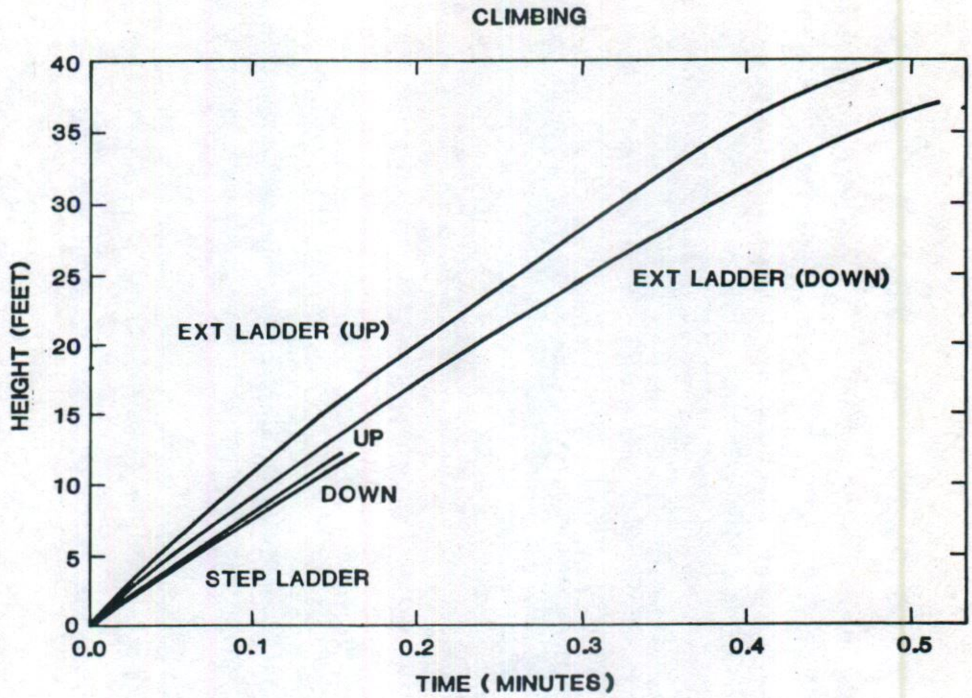

Figure 15-3. Climbing Rates—Extension Ladder, Stepladder

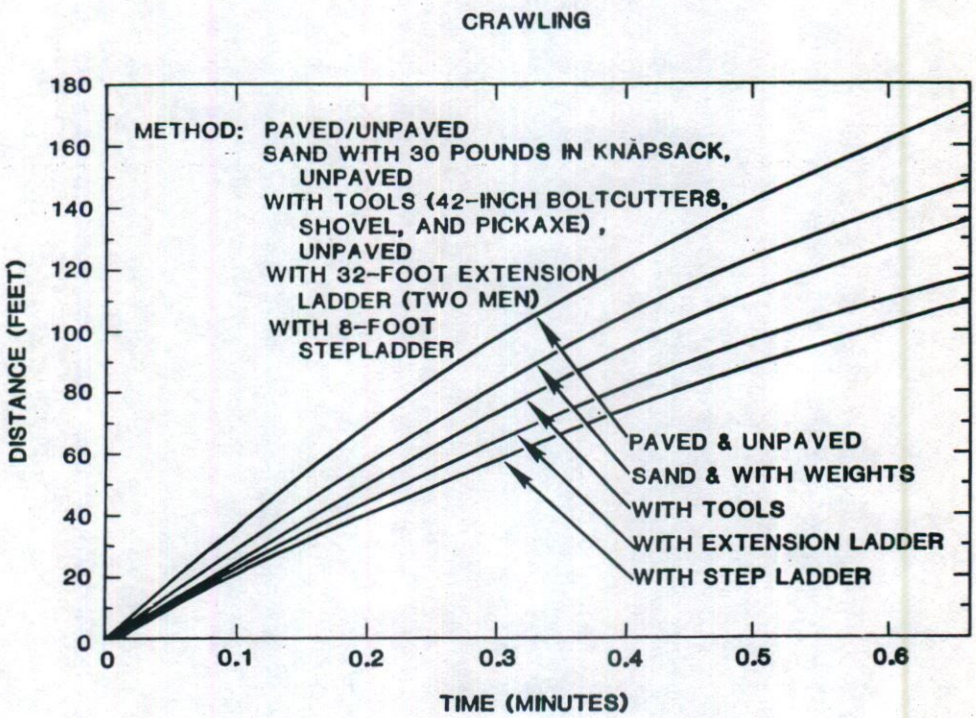

Figure 15-4. Crawling Rates

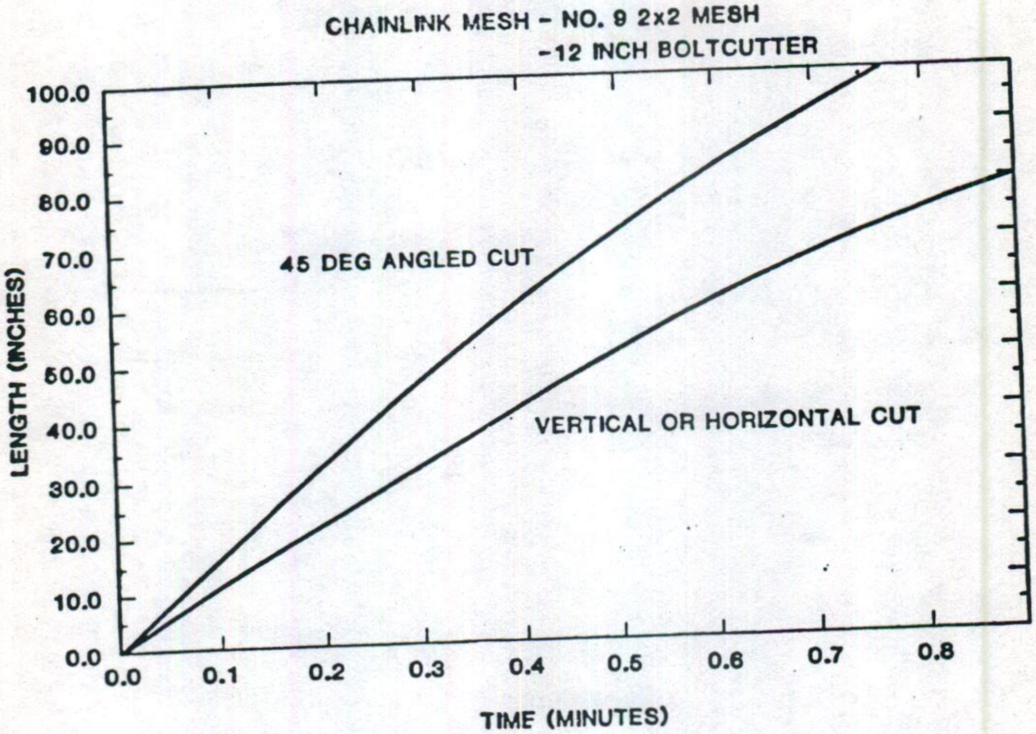

Figure 15-5. Cutting Rates—12-Inch Boltcutters (Chain-Link Mesh Fabric)

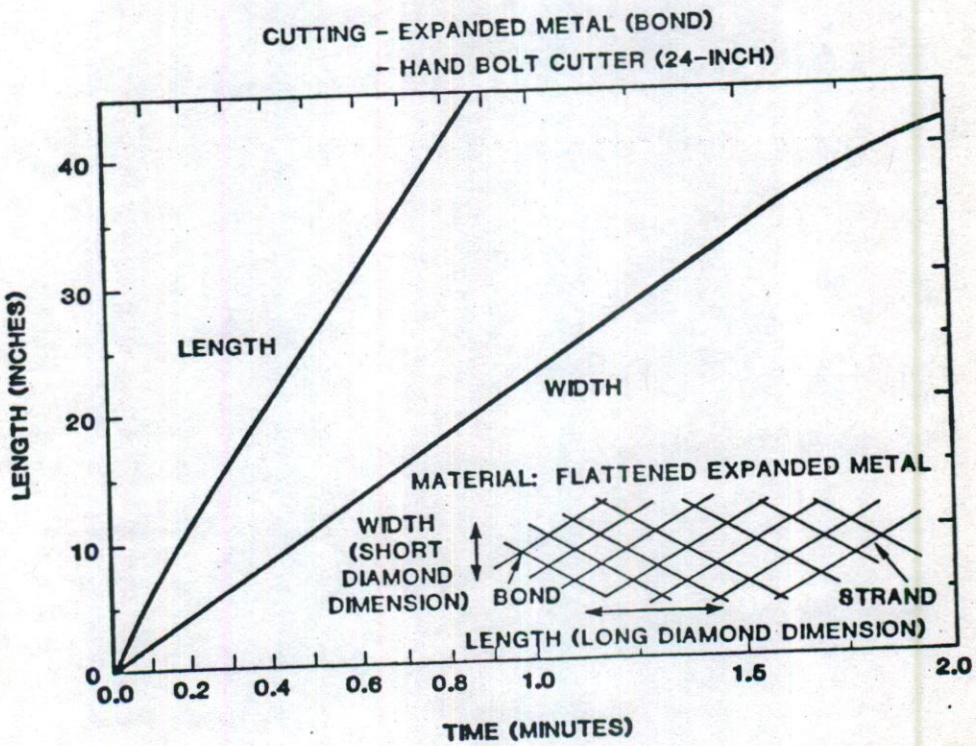

Figure 15-6. Cutting Rates—Bond Cut-Through, 24-Inch Boltcutters (Flattened Expanded Metal—1½-Inch, 9-Gauge)

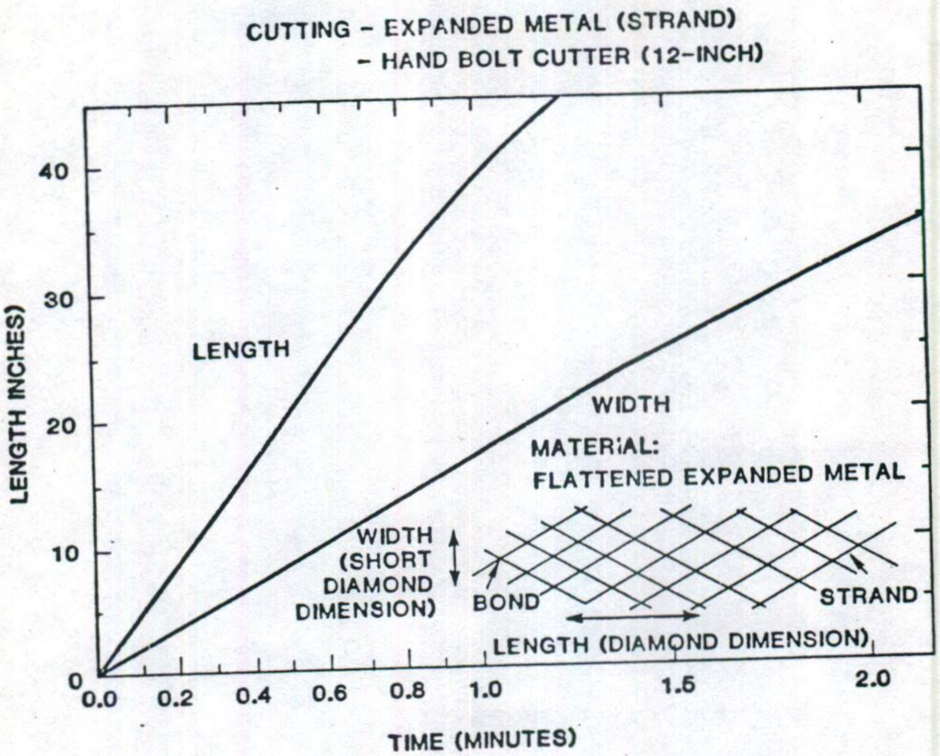

Figure 15-7. Cutting Rates—Strand Cut-Through, 12-Inch Boltcutters (Flattened Expanded Metal—1½-Inch, 9-Gauge)

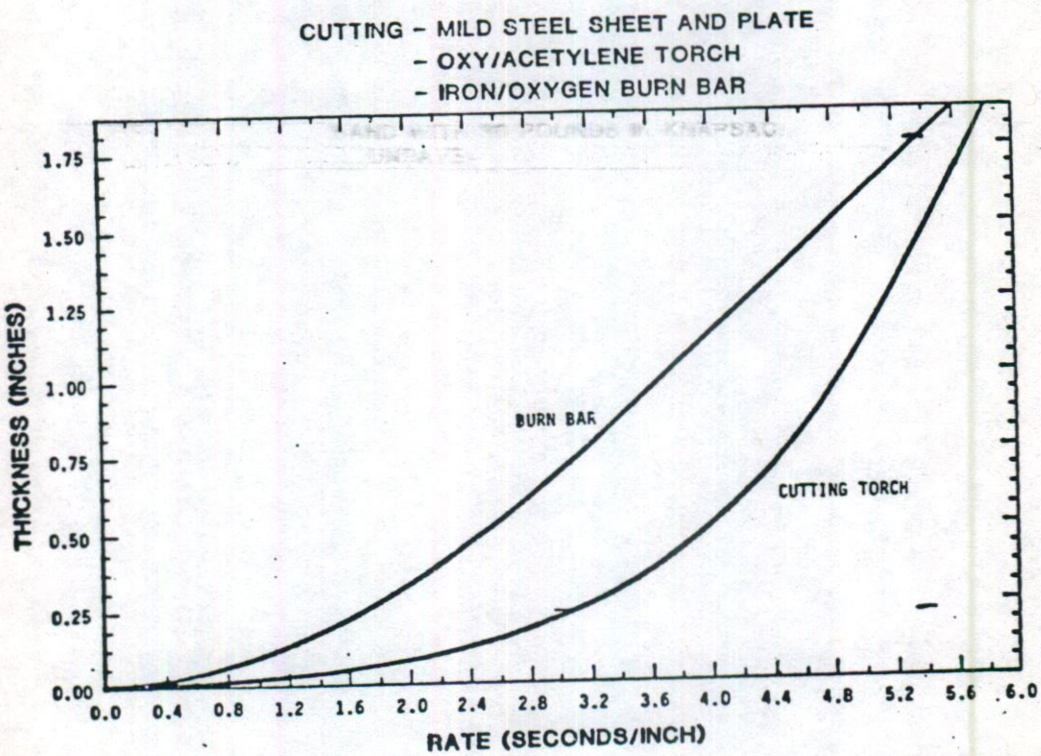

Figure 15-8. Cutting Rates—Oxyacetylene Cutting Torch or Iron-Oxygen Burn Bar (Mild Steel Sheet and Plate)

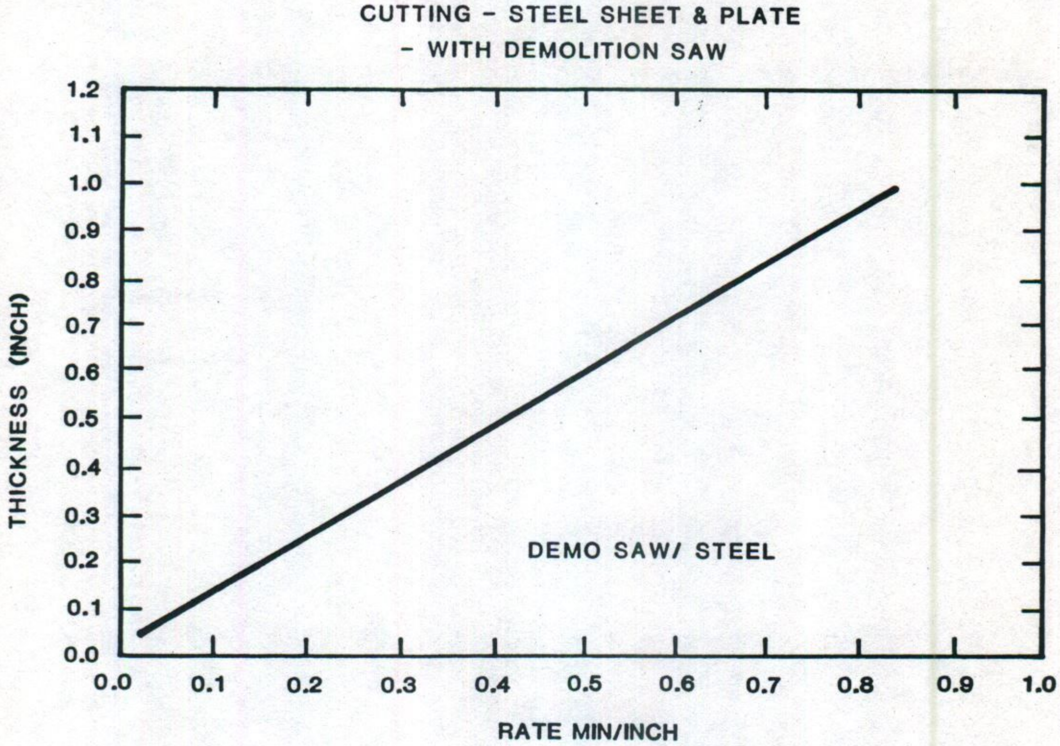

Figure 15-9. Cutting Rates—Demolition Saw (Mild Steel Sheet and Plate)

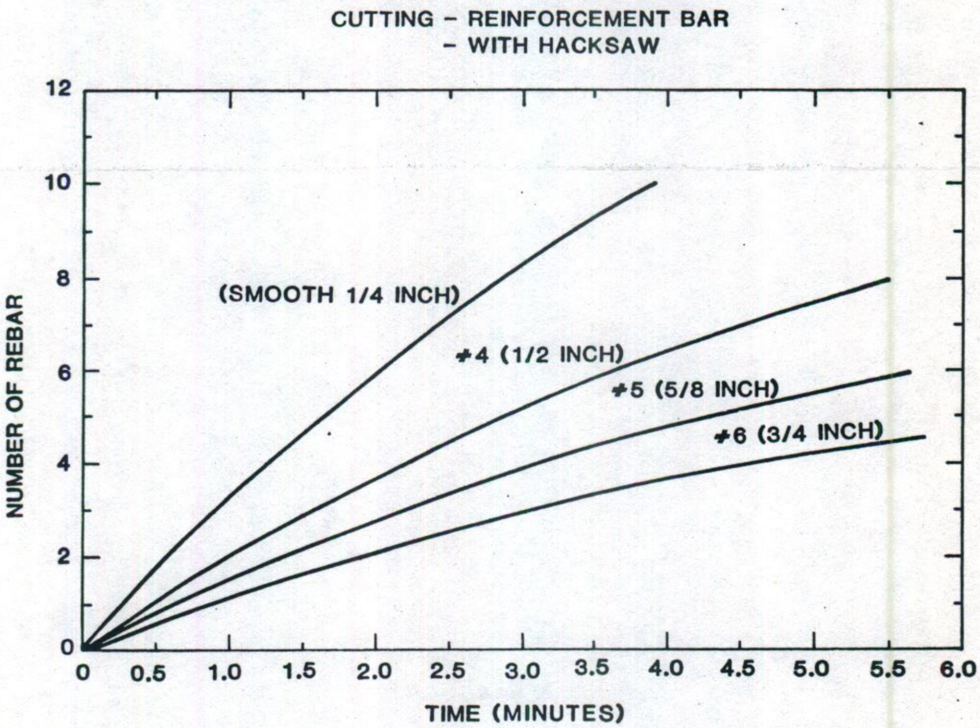

Figure 15-10. Cutting Rates—Hacksaw (Reinforcement Bar)

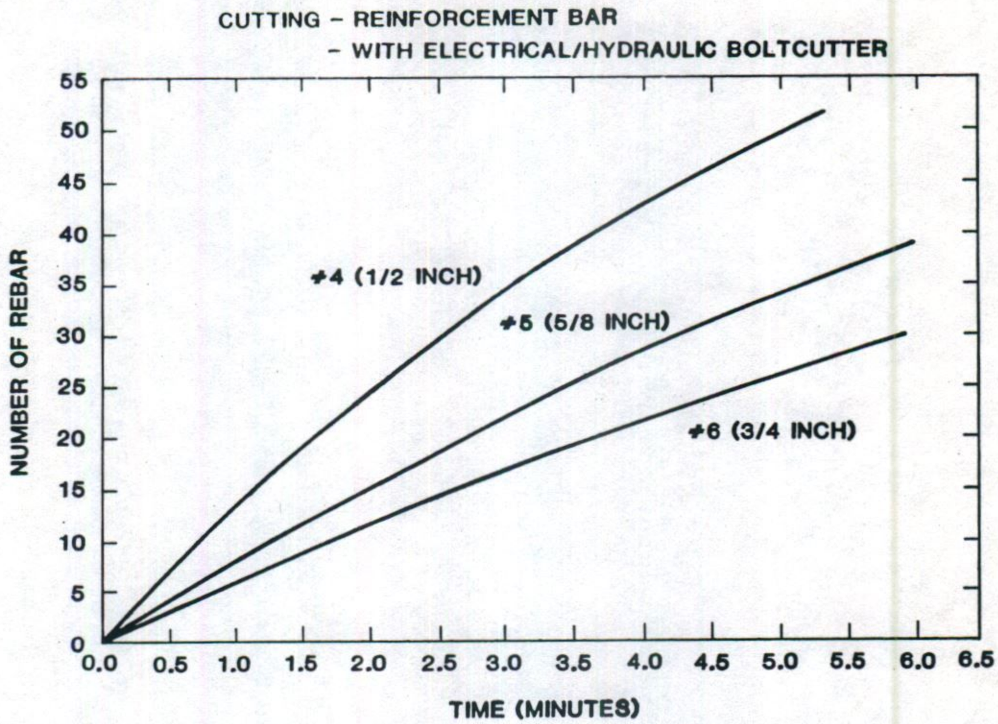

Figure 15-11. Cutting Rates—Electrical/Hydraulic Boltcutters (Reinforcement Bar)

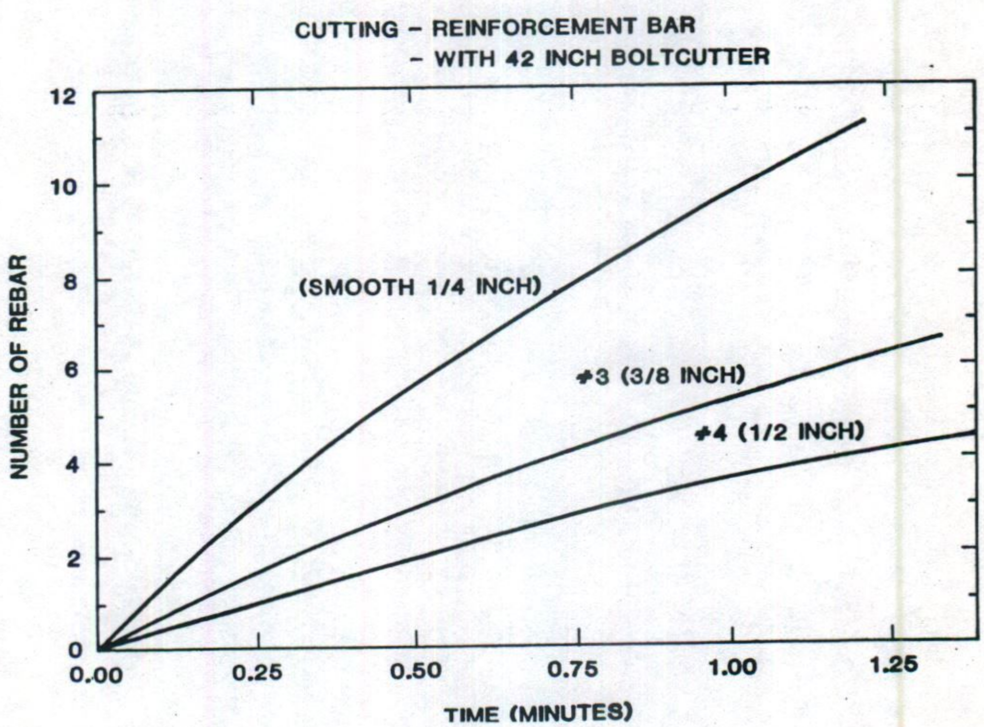

Figure 15-12. Cutting Rates—42-Inch Boltcutters (Reinforcement Bar)

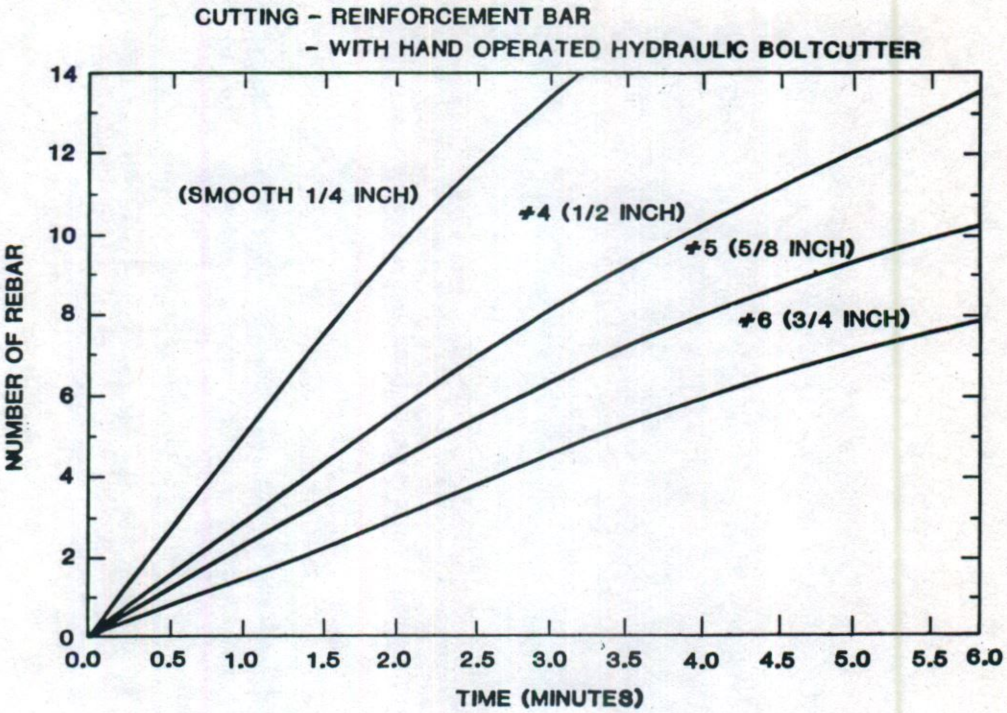

Figure 15-13. Cutting Rates—Hand-Operated Hydraulic Boltcutters (Reinforcement Bar)

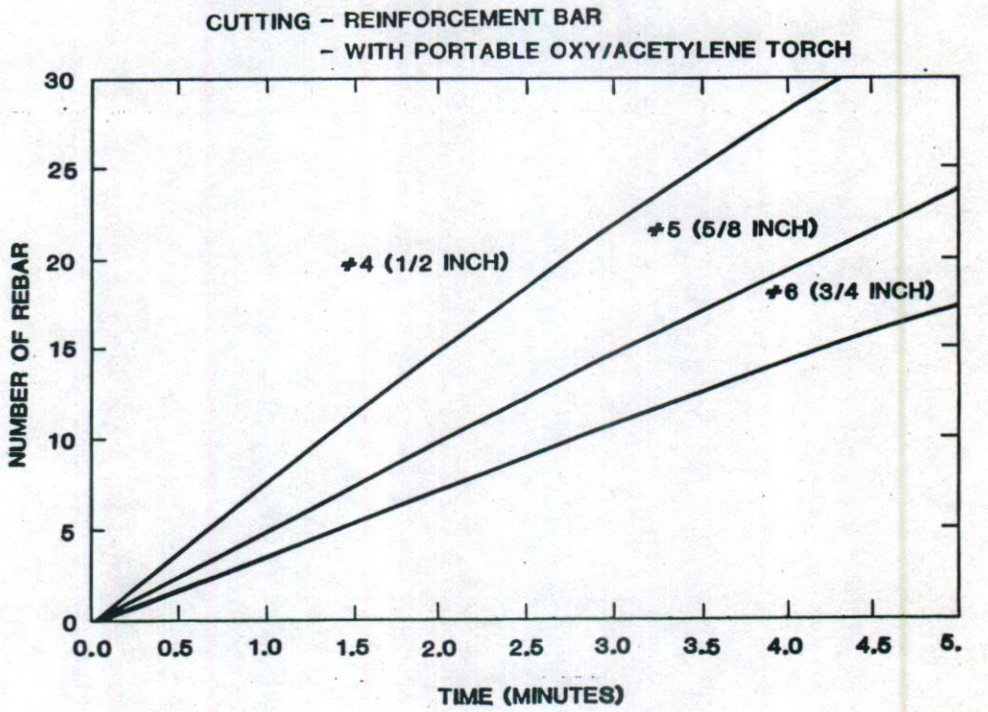

Figure 15-14. Cutting Rates—Portable Oxyacetylene Cutting Torch (Reinforcement Bar)

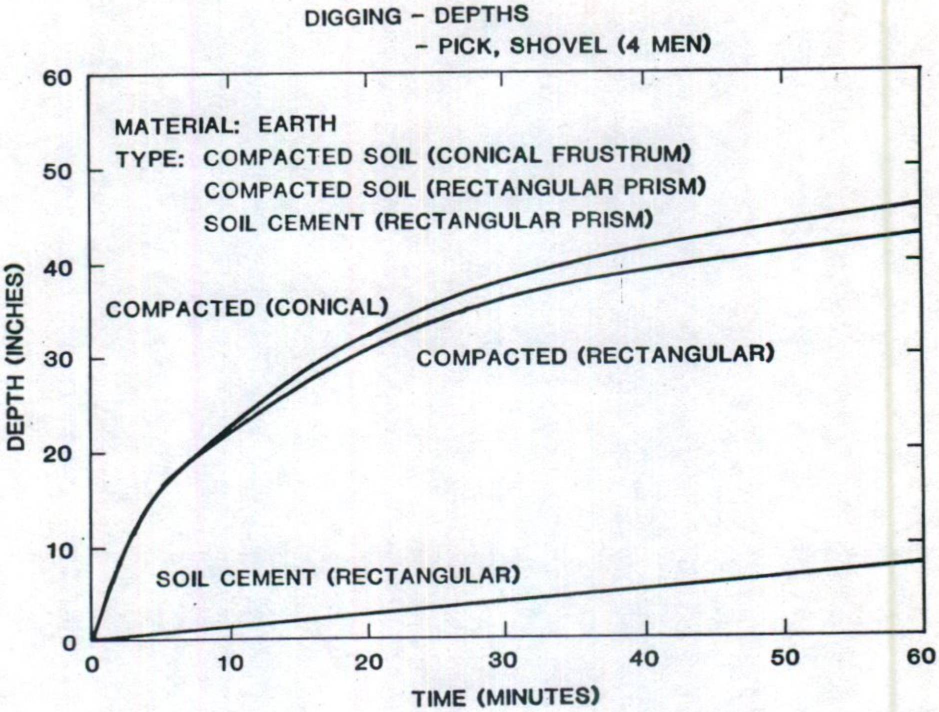

Figure 15-15. Digging Rates—Various Depths of Earth (Pick, Shovel, Four Men)

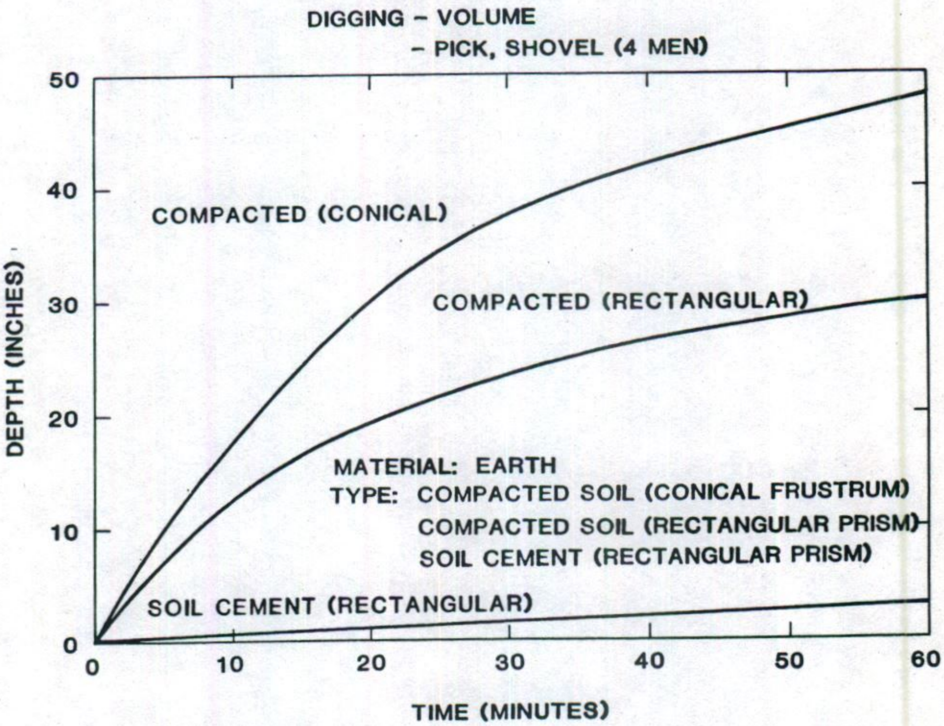

Figure 15-16. Digging Rates—Various Volumes of Earth (Pick, Shovel, Four Men)

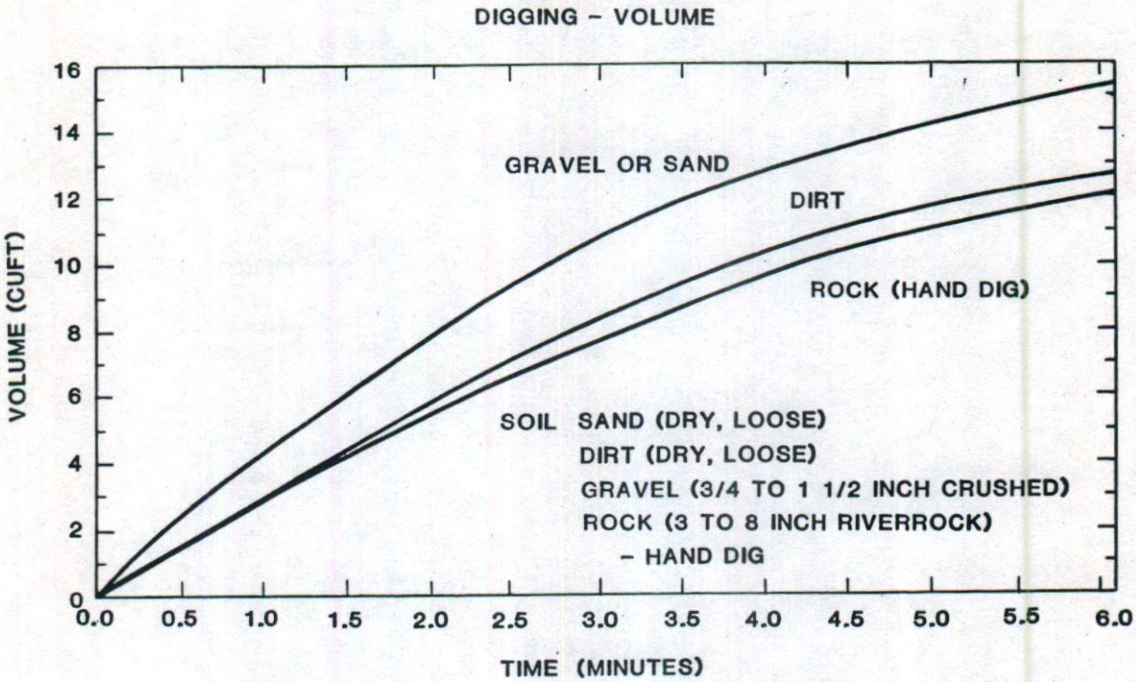

Figure 15-17. Digging Rates—Various Types of Material (Shovel, One Man)

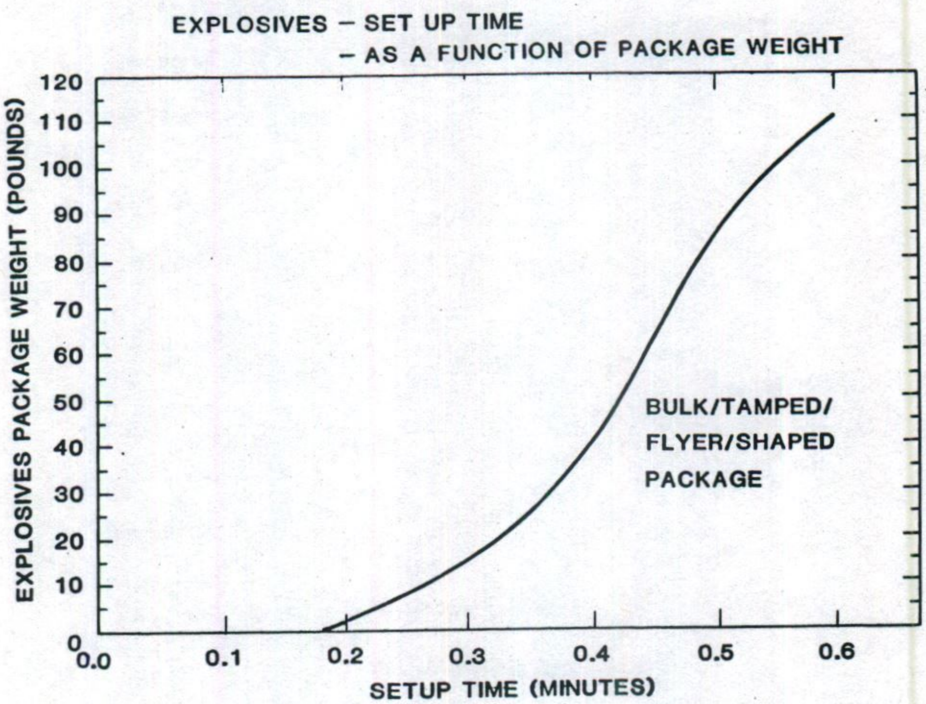

Figure 15-18. Explosives—Set-Up Time as a Function of Package Weight

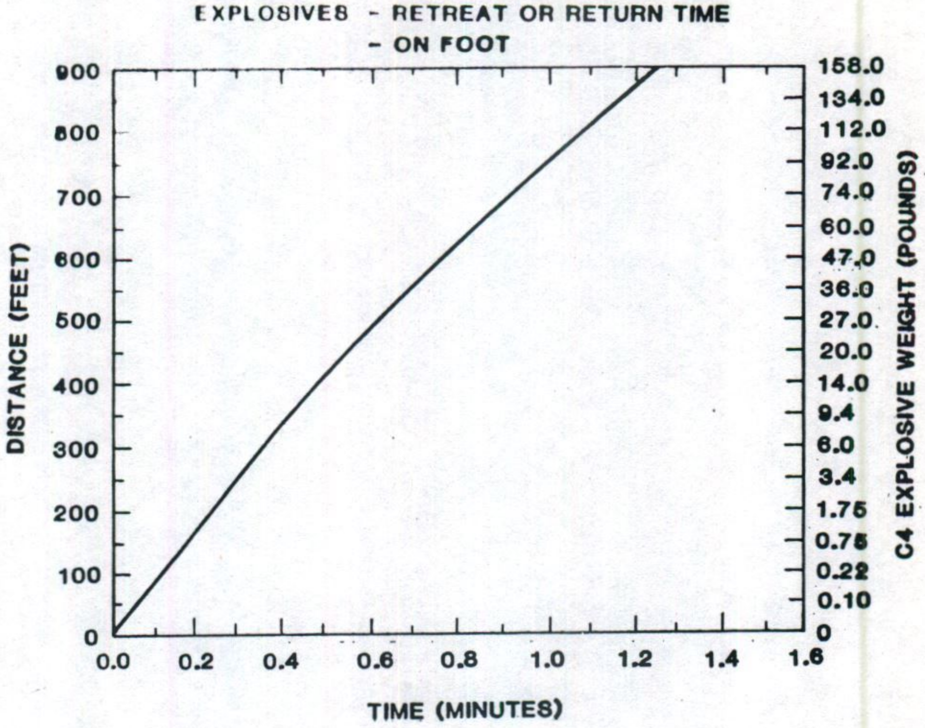

Figure 15-19. Explosives—Retreat or Return Time (On Foot)

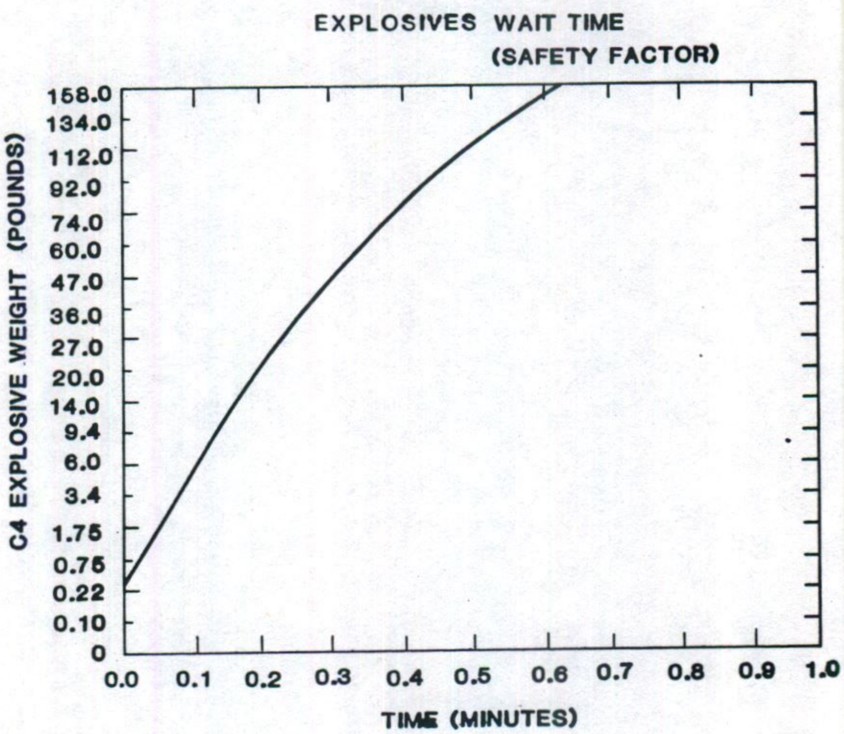

Figure 15-20. Explosives—Wait Time

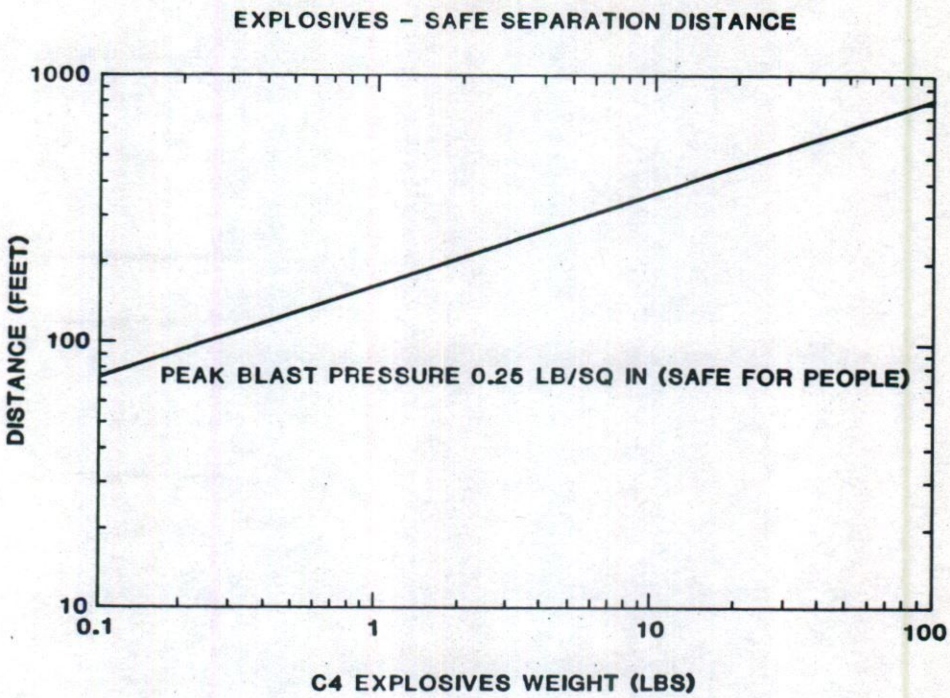

Figure 15-21. Explosives—Safe Separation Distance, Explosives and Humans

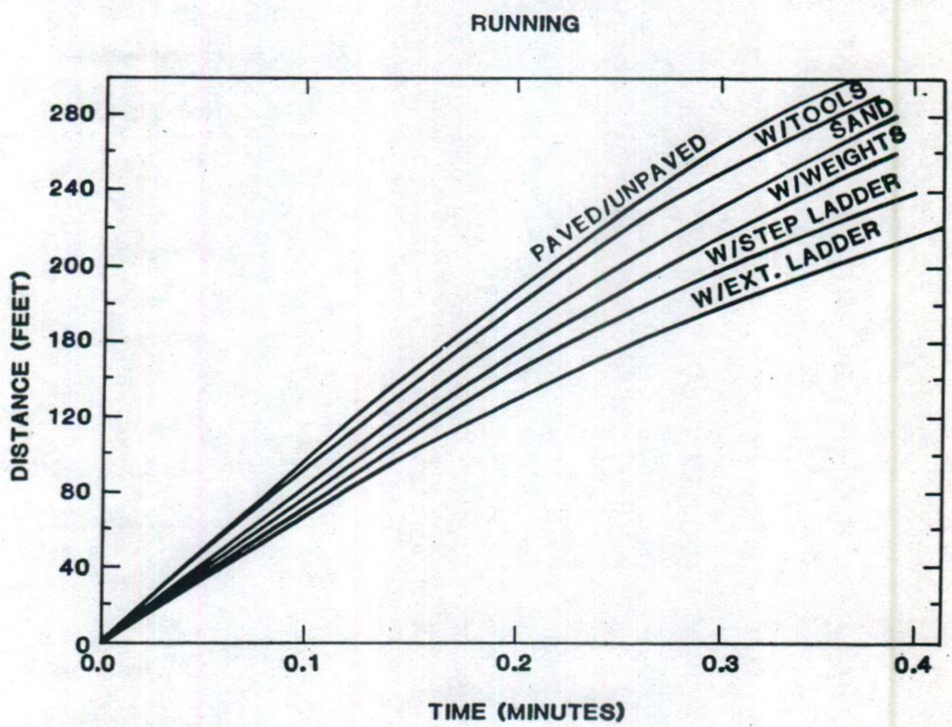

Figure 15-22. Running Rates

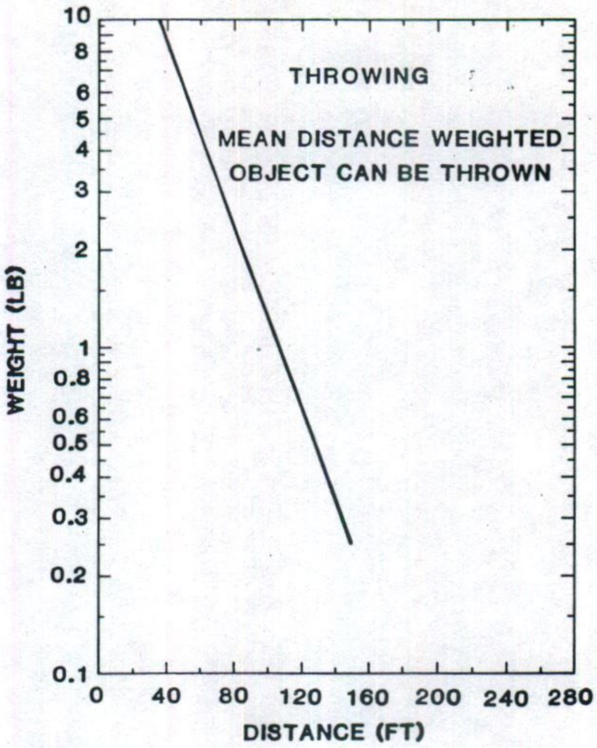

Figure 15-23. Throwing Rates

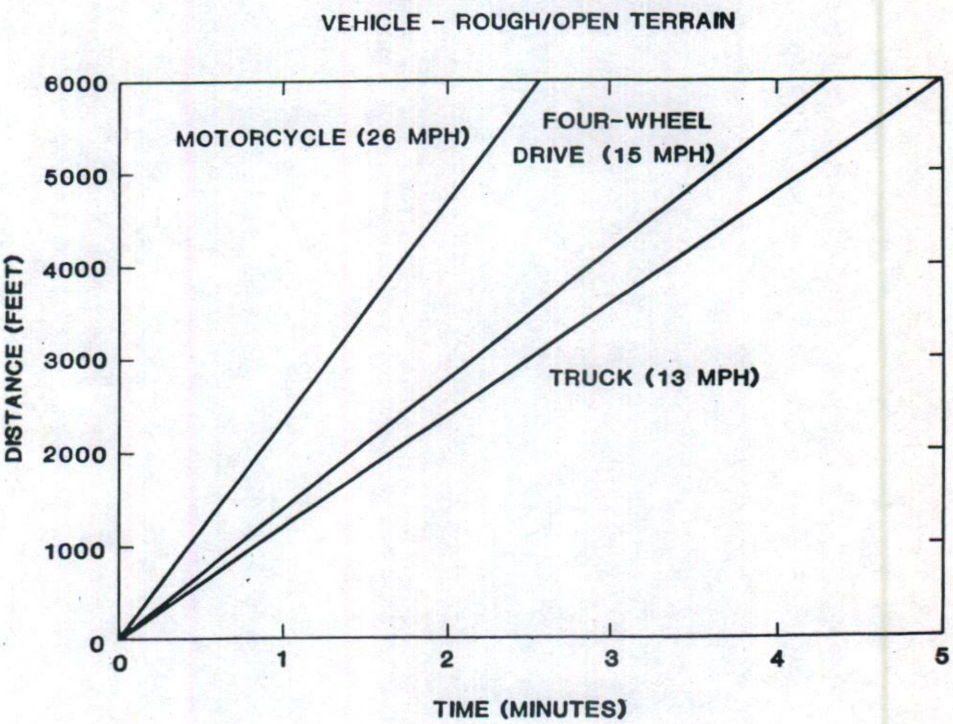

Figure 15-24. Vehicle Rates—Rough/Open Terrain (Experienced Drivers)

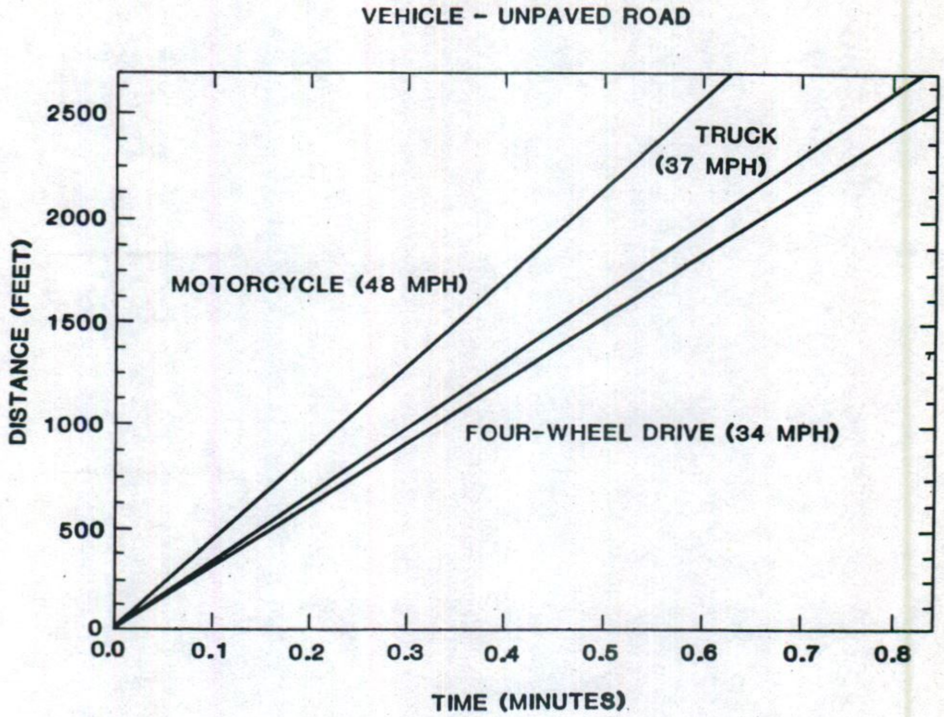

Figure 15-25. Vehicle Rates—Unpaved Road (Experienced Drivers)

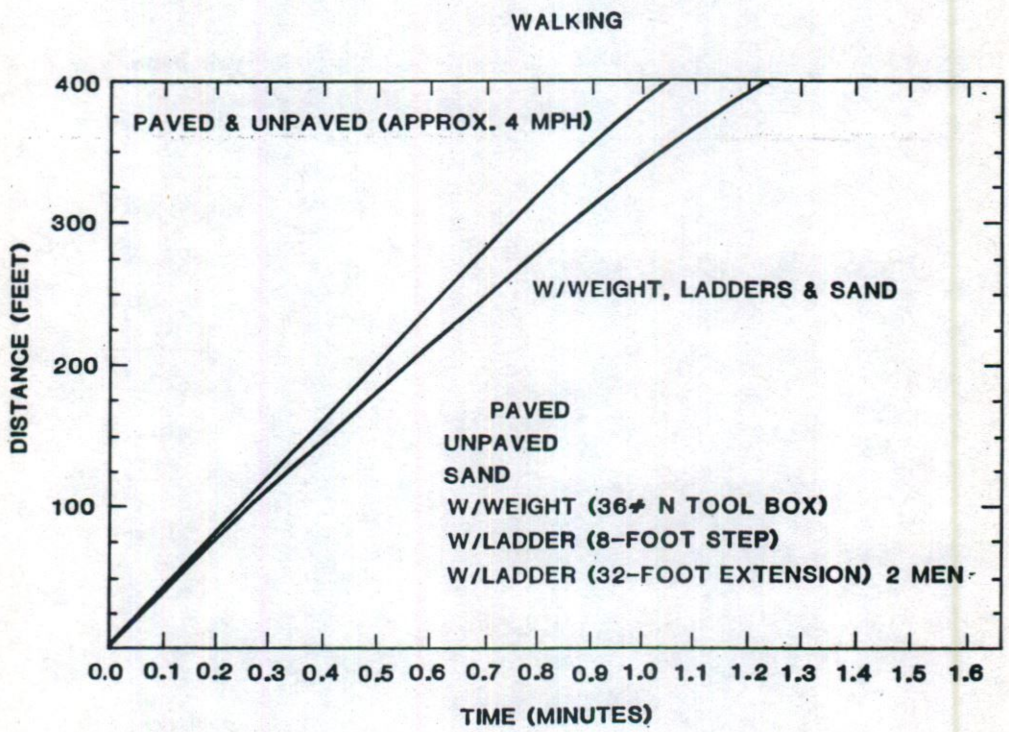

Figure 15-26. Walking Rates

TABLE 15-1

Vehicle Access Door Cutting Rates — 18-Gauge, Corrugated Steel Rollup

Tool	Minutes/Inch
Demolition saw	0.03
Oxygen lance	0.03
Oxyacetylene torch	0.08
Saber saw	0.13

TABLE 15-2

Mild Steel Wire Mesh Screens Cutting Rates

Size (inches)	Tool	Minutes/ Cut
2¼ x 2¼ x ½ dia.	Oxyacetylene torch	0.18
	Demolition saw	0.31
	Hydr. boltcutter	0.83
1¼ x 1¼ x ⅜ dia.	Oxyacetylene torch	0.08
	Demolition saw	0.13
1¼ x 1¼ x ¼ dia.	Oxyacetylene torch	0.06
	Demolition saw	0.07
	Hand boltcutter	0.28
¾ x ¾ x 0.207 dia.	Oxyacetylene torch	0.03
	Demolition saw	0.06
⅝ x ⅝ x 0.162 dia.	Oxyacetylene torch	0.02
	Demolition saw	0.05

TABLE 15-3

Steel Panel Cutting Rates

Description	Tool	Minutes/ Inch
Riveted steel panel per MIL-G-18014B, Type A	Oxygen lance	0.06
	Demolition saw	0.07
Grip-strut panel per Fed. Spec. #RR-G-1602	Oxygen lance	0.04
	Demolition saw	0.03
2-in. wire mesh panel, 9-gauge steel wire	Oxygen lance	0.04
	Demolition saw	0.03

TABLE 15-4

Mild Steel Bar Cutting Rates

Diameter (inches)	Tool	Minutes/Cut
½	Oxygen lance	0.08
	Demolition saw	0.14
	Boltcutters manual	0.29
¾	Oxygen lance	0.09
	Oxyacetylene torch	0.21
	Demolition saw	0.25
	Hacksaw, manual	1.36
⅞	Oxygen lance	0.14
	Demolition saw	0.54
1	Oxygen lance	0.14
	Oxyacetylene torch	0.31
	Demolition saw	0.60
	Hacksaw, manual	3.00
1½	Oxygen lance	0.22
	Oxyacetylene torch	0.44
	Demolition saw	2.51
	Hacksaw, manual	5.00
1¾	Oxygen lance	0.28
	Oxyacetylene torch	0.58
	Demolition saw	5.00
	Hacksaw, manual	7.50

TABLE 15-5

Cutting 24-Gauge Steel 24 x 24-Inch Sheet Metal Ducts

Tool	Mode		Minutes/ Inch
	Attack	Cut Through	
Handax & hammer	Interior	Top	0.14
		Side	0.11
		Bottom	0.06
Hatchet & Saber saw	Interior	Top	0.11
		Bottom	0.08
Drill & Saber saw	Interior	Top	0.17
		Side	0.23
Fire axe	Exterior	Side	0.05
Demolition saw	Exterior	Side	0.04
Hand metal shears	Exterior	Bottom	0.20

TABLE 15-6

Sheet Metal Ducts
Crawling Rates through Horizontal Ducts

Size (inches)	Area	ft/min	min/ft
18 x 18	324	67	0.015
24 x 24	526	100	0.010
18 x 36	648	100	0.010
36 x 18	648	100	0.010

TABLE 15-7

Sheet Metal Ducts
Climbing Rates through Vertical Ducts

Duct Size	UP		DOWN	
(inches)	ft/min	min/ft	ft/min	min/ft
24 x 24	5.8	0.17	9.1	0.11
18 x 18	2.3	0.44	8.3	0.12

BARRIER DATA BASE

The barrier data base is a tabular presentation of barrier penetration times and other penetration parameters arranged as a function of the various barrier elements (ceilings, doors, fences, floors, etc.). The data-base tables are presented in this section alphabetically and may be correlated with appropriate chapter headings of this handbook, e.g., for tables on fences and gates, refer to Chapter 3: "Perimeter Barriers." The following paragraphs describe the table presentation format according to column headings.

Barrier Description — The barrier descriptions are necessarily brief. For a more detailed description of the barrier (or test), the source is referenced.

Number of People — This column shows the number of people necessary to efficiently perform the penetration functions. Fewer people might achieve penetration, but a longer time would probably be required. More people would not appreciably shorten the penetration time. There is no relation between the number of people required for efficient penetration of an individual barrier and the postulated size of an attack force required for a complete adversary scenario.

Penetration Equipment — This column lists the equipment used (or postulated if the barrier and/or penetration functions were estimated) to achieve penetration. Weights of individual tools are not listed. Weights of explosive tools are shown in parentheses. Equipment not actually used in the penetration is not shown, i.e., trucks required to transport equipment are omitted; trucks required to penetrate barriers are included.

Total Equipment Weight — The weights of all tools (including explosives but excluding trucks, etc.) are shown.

Penetration Time (Minutes) — The time required to produce a hole in the barrier sufficient to crawl through and the time required for one person to actually crawl through the hole are tabulated as the mean time.

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ATTACK TOOLS

Tool Description

Compiling rates for the performance of different jobs encompasses many materials, attack methods, and tools. The effective use of tools determines the time required to breach or penetrate most barriers. Tools used to attack barriers may range from small hand tools, such as boltcutters, to large, heavy items, such as mobile air compressors. Categories of tools include (1) hand tools, (2) power tools, (3) thermal tools, (4) explosives, and (5) heavy equipment (see Figure 15-39). A brief description of the most commonly used tools, together with their effectiveness against barriers, is presented in the following subsections.

Sledgehammer

The sledgehammer may be an effective tool for forcible barrier penetration. It is used singularly or in conjunction with other tools. The most effective sledgehammer appears to be in the 6- to 16-pound range; the 10-pound size is preferred by most operators. In sustained attacks on a concrete wall, a sledgehammer operator averages approximately 2 seconds per blow. For attacks of 10 to 15 minutes, operators usually rest 3 minutes for each minute of work.

Maul or Axe

The cutting maul or fireman's axe can be used on weaker materials such as wood, plaster walls, roofing materials,

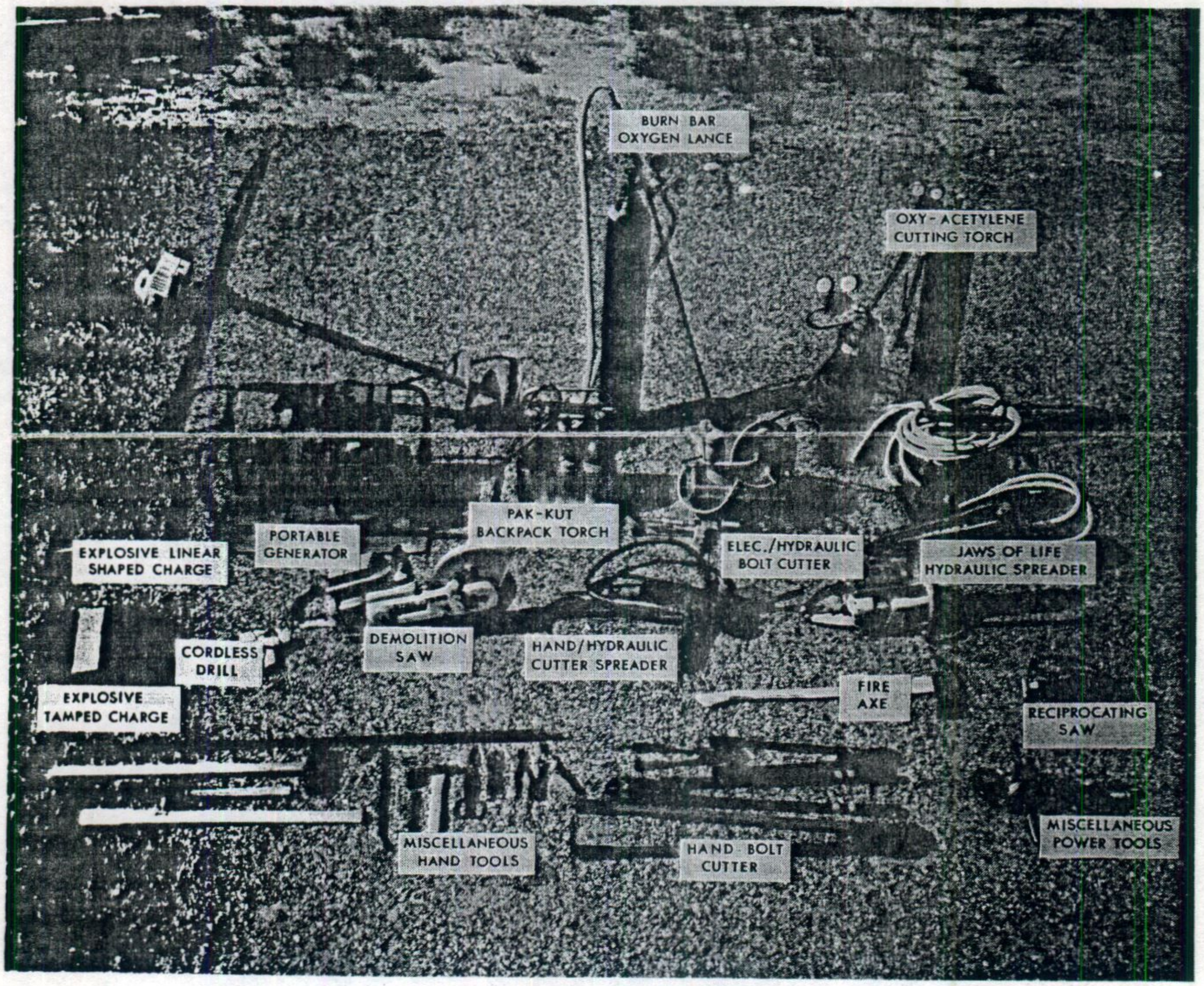

Figure 15-39. Attack Tools

and doors. The maul and the axe weigh approximately 6 pounds each and are used at the rate of 2 seconds per blow. They are very effective in penetrating composite walls, wood or thin metal pedestrian doors, and built-up roofs consisting of corrugated metal, rigid insulation, and bituminous materials.

Boltcutters

Boltcutters are used for cutting chains, padlocks, chain-link mesh, grillwork, and rebar. Boltcutters range in size from 12 to 42 inches in length. The 12-inch boltcutters are used against lighter materials, while the 42-inch size is used against cables, heavy chains, and ⅜- to ½-inch rebar. The rate of use per minute ranges from 30 cuts for chain-link mesh or flattened expanded metal to 4 cuts for ½-inch rebar.

Wrecking Bar

Wrecking bars can be used to jimmy doors or windows and to lift vents or covers. Common sizes range from 12 to 30 inches in length. About 15 seconds is required to pry a door open, while about 30 seconds is needed to forcibly open a window or simple vent.

Circular Saw

A gasoline-powered, circular saw can cut any of the materials likely to be encountered in structural barriers including concrete, masonry, steel, and wood. Depth of a cut is limited by blade size, but a cut is normally 2 to 5 inches deep. The saw is usually most effective against thin materials, such as corrugated metal decking, industrial pedestrian doors, or chain-link mesh. Composite walls or roofs are also easily cut. Cutting rates range from 1 second per foot for chain-link mesh to 10 seconds per lineal inch per 3-inch depth for reinforced concrete.

Rotohammer

A rotohammer combines the rotary action of a drill and the pounding action of a small sledgehammer. It is usually used to drill holes in concrete or masonry. When used to open man-sized holes, the rotohammer is used in conjunction with a sledgehammer and punch. A man-sized hole is obtained by drilling a pattern of holes partially through the concrete and spalling off the interior using he sledgehammer and punch. After one or more iterations of this process, the thickness of the barrier is reduced to such a degree that a sledgehammer can be used to break through a small area. Drilling rates with the rotohammer are a function of barrier composition and drill size. Drilling times for 1-inch holes range from 3.5 to 10.5 seconds per inch of depth, depending on the type of material.

Hydraulic Power Pack

A hydraulic power pack consists of an electrical motor coupled to a hydraulic pump. The pack is used with hose and attachments to lift, bend, or cut. A hydraulic ram can be used to bend rebar or force apart a door frame. A hydraulic cutter can be used to cut bars or rods up to 1 inch in diameter. The cutter can be either locally or remotely controlled. Bending or cutting rates primarily depend upon operator speed since the tool reaches peak pressure and full piston stroke in a few seconds. Cutting ¾-inch rebar requires approximately 10 seconds per cut.

Cutting Torch

An oxygen-acetylene torch is commonly used for gas welding or cutting. Flame cutting of ferrous metals requires only basic manual skills. One tank of oxygen and one tank of acetylene, together with pressure regulators, hoses, a torch, and cutting attachment are all that are needed to penetrate most existing metal doors and utility ports. A small backpack model weighing 56 pounds and having a cutting rate of approximately 20 inches/min for ¼-inch-thick mild steel can be operated for 1 hour. Larger equipment (with 120-ft^3 tank capacity) can cut at the same rate but for a period of time exceeding 3 hours.

Oxy-Lance (Burn Bar)

The oxy-lance or burn bar is another thermal tool used for cutting. It can burn through most existing barriers, including concrete. The burn bar consists of a metal tube packed with a number of treated wires coupled to a lever control handle which is connected to an oxygen source. Once the tip of the lance is heated to approximately 1500°F by an acetylene torch and oxygen is supplied, the lance begins to burn at temperatures up to 10,000°F. The lance is self-comsumable. A 10-foot-long lance will be consumed in approximately 3.5 minutes, and a standard tank of oxygen (120 cubic feet) can supply oxygen for 3½ units. Typical cutting times per lineal inch are 2 seconds for ¼-inch-thick steel plates and 4 seconds for 1-inch-thick steel plates. The burn bar can also remove reinforced concrete at the rate of approximately 4 s/inch^3.

Generator

The gasoline-powered generator can be used to supply electricity for most power tools which are used to penetrate barriers. Most portable models in the 3000- to

5500-watt (generator), 8- to 13-horsepower (engine) range are adequate to power all the electrical tools listed in Table 15-9. Since most hand-carried generators weigh from 110 to 170 pounds, two men are required to utilize them.

Explosives

Bulk charges of explosives ranging in weight from a few grams to several tens of pounds could be used on reinforced concrete walls, expanded metal- concrete walls, and steel doors. Plastic explosives can be molded to fit contours. Most bulk charges are formed from standard military demolition charges or commercially available 50-pound quantities.

Satchel charges consist of a number of standard demolition charges packaged in a canvas case. Satchel charges are used primarily in breaching barriers where shaped bulk charges are not required. The standard military satchel charge consists of 20 pounds of explosives and can be fired electrically or by a detonating cord.

Linear shaped charges can be used to cut through doors, posts, walls, or similar barriers. The V-shaped charge cuts a narrow slot along its entire length. Linear shaped charges can be formed to cut out any contour or size. Commercial, linear shaped charges are available in quantities up to 11,100 grains (1.6 pounds) per foot.

A platter or flyer-plate charge consists of a metal plate with formed explosives attached to one side. A Teflon®, rubber, or foam buffer can be used between the explosives and the plate. The platter charge is positioned a predetermined distance from the barrier in such a manner that the plate will be propelled toward the barrier. The explosives detonation propels the plate at optimum velocity into the barrier.

Tamping material is used to direct more explosive force toward a barrier. Metal plates, sandbags, earth, and water have been used as tamping materials. The explosives are detonated between the barrier and the tamping material. Tamping material can also be used in conjunction with platter charges to increase the plate velocity.

Tool Weights

Nominal weights for tools within each of the tool categories are tabulated in Tables 15-8 through 15-12.

TABLE 15-8

Hand Tool Category

Item	Weight (Pounds)
Hammer	<6
Suction Cup	1
Sledge	5-10
Sledge	10-16
Sledge	≥16
Hand Tools	
Cutting Maul	<6
Cutting Maul	≥6
Axe	2-5
Fire Axe	10
Lock-Picking Tools	0.5
Punch	<0.5
Chisel	0.5
Saw, Wood (Carpenters)	1
Saw, Metal (Hacksaw)	0.5
Boltcutters, <24 inches	5-10
Boltcutters, ≥24 inches	10-20
Hand Hydraulic Boltcutters	10
Strap Wrench	0.5
Pliers, <8 inches	0.5
Pliers, ≥8 inches	0.5
Pliers, Vise Grip, Med.	1.0
Shears, Sheet Metal	0.5
Tin Snips	0.5
Rifle, 30-06 w/Scope	15
Hand Gun, .357 Magnum	3
Hand Gun, .38 Super	3
Hand Gun, .44 Magnum	3.5
Brace and Bit	2
S-Hook, 18-inch, Made of Rebar	0.5
6-foot Pry Bar	15
Wrecking Bar	<18
Wrecking Bar	≥18
Wrecking Bar, <35 inches	3
Battering Ram	50
Shovel	5
Pick	5-10
Posthole Digger	5
Auger	10-50
Grappling Hook, 3 barbs	3
Yellow Tape	
Carpet, 4 x 15 foot	40
Plywood, 0.375-inch, 4- x 8-foot	25
Plank, <1-inch-thick	
Plank, 1- to 2-inch-thick	
Plank, 2- to 4-inch-thick	
Timber, ≥4-inch-thick	
10-foot Pipe, 2-inch outer diameter	25
Plywood, 0.375-inch, 2- x 8-foot	12
Tarpaulin	
Ladder	
Ladder, Step	
Wire Cable, 0.25-inch Steel, 25 feet	3
Rope, 0.5-inch Nylon, 50 feet	35

TABLE 15-9

Power Tools Category

Item	Weight (Pounds)
Saw, Circular, Steel Blade, <8-inch Blade	20-30
Saw, Circular, Steel Blade, 8- to 12-inch Blade	20-30
Saw, Circular, Steel Blade, ≥12-inch Blade	20-30
Saw, Circular, Abrasive Blade, <12-inch Blade	20-30
Saw, Circular, Abrasive Blade, ≥12-inch Blade	20-30
Saw, Circular, Diamond Blade, <12-inch Blade	20-30
Saw, Circular, Diamond Blade, ≥12-inch Blade	20-30
Saw, Circular, Carbide-Tipped Blade, Gasoline-powered	35
Chainsaw, <16-inch Bar	10-15
Chainsaw, ≥16-inch Bar	15-30
Saw, Circular, Hubless, Steel Blade	20-30
Saw, Reciprocating (Sabre Saw)	3
Electric Powered Hydraulic Boltcutters	17
Gas Powered Hydraulic Boltcutters	30
Drill, 0.25-inch Chuck	2
Drill, 0.375-inch Chuck	3
Drill, 0.5-inch Chuck	6
Drill, Cordless 0.25-inch Chuck	4
Drill, Cordless 0.375-inch Chuck	6
Drill, Cordless 0.5-inch Chuck	8
Drill, Diamond Core	90
Rotohammer, Drill	15
Rotohammer, Chisel	15
Hydraulic Tools, Hand-Operated Pump	
Hydraulic Tools, Power PAC Operated Pump	
Lights, Portable, Electric	
Lights, Portable, Other	
Jackhammer, Pneumatic, with Bits	100
Auger, Two-man	

TABLE 15-10

Thermal Tools Category

Item	Weight (Pounds)
Powder for Powder Lance	0-50
Powder for Powder Lance	50-100
Powder for Powder Lance	<100
Thermal Tools	
Cutting Torch with Tanks, Oxyacetylene	55
Cutting Torch with Tanks, Oxyacetylene	200
Cutting Torch with Tanks, Mapp	55
Cutting Torch Hand, w/Powder Attach, Linde C-63	100
Cutting Torch, Oxygen-Fed, Electric Arc	150
Rocket Torch, UTC	200
Oxy-Lance, Small Tank, Gauge, Hose, Two Bars	100
Lance, Powder, Linde Acl-4	150
Oxy-Lance, Large Tanks, Gauge, Hose, Bars	200-300

TABLE 15-11

Heavy Equipment Category

Item	Weight (Pounds)
Truck, <1 Ton	3500
Truck, ≥1 Ton	4500
Truck, Van	3000
Car, Passenger, Medium	2500
Car, Passenger, Small	2000
Generator, 4.5-kW, Trailer-Mounted, Gasoline-Powered	500
Generator, 3-kW, Gas-Operated	75
Compressor, Trailer-Mounted, Gasoline-Powered	600
Gun, 20-mm	175
Gun, 40-mm	200

TABLE 15-12

Explosives Category

Item	Weight (Pounds)
Explosives, Bulk	0-5
Explosives, Bulk	5-10
Explosives, Bulk	10-20
Explosives, Bulk	20-50
Explosives, Bulk	50-100
Explosives, Bulk	≥100
Explosives, Satchel Charge	0-10
Explosives, Satchel Charge	10-20
Explosives, Satchel Charge	20-30
Explsoives, Satchel Charge	30-50
Explosives, Satchel Charge	50-75
Explosives, Detonating Cord, <100 Grains per foot	
Explosives, Detonating Cord, ≥100 Grains per foot	
Explosives, Linear Shaped Charge, <100 Grains per foot	
Explosives, Linear Shaped Charge, 100 to 500 Grains per foot	
Explosives, Linear Shaped Charge, 500 to 2000 Grains per foot	
Explosives, Linear Shaped Charge, ≥2000 Grains per foot	
Explosives, Linear Shaped Charge, 3.5 oz, 250 Grains per foot	19
Explosives, Linear Shaped Charge, 1.9 oz, 250 Grains per foot	9
Explosives, Linear Shaped Charge, 5.6 oz, 250 Grains per foot	27
Explosives, Linear Shaped Charge, 5.6 oz, 550 Grains per foot	26
Explosives, Linear Shaped Charge, 3.4 oz, 550 Grains per foot	11
Explosives, Conical Shaped Charge	<2
Explosives, Conical Shaped Charge	2-5
Explosives, Conical Shaped Charge	5-10
Explosives, Conical Shaped Charge	10-20
Explosives, Conical Shaped Charge	≥20
Explosives, Platter Charge, Total Weight	<10
Explosives, Platter Charge, Total Weight	10-25
Explosives, Platter Charge, Total Weight	25-50
Explosives, Platter Charge, Total Weight	50-100
Explosives, Platter Charge, Total Weight	≥100
Explosives, Bangalore Torpedo	20
Tamping Material (Typical) 2 to 3 times explosive weight	

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